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ABSTRACT

Reviewed in seven author contributed chapters are findings of experimental psychology relevant to the education of handicapped children in the areas of sensory processes, visual perception, memory, cognition and language development, sustained attention and impulse control, and personality and social development. Noted in an introductory chapter are the nature and incidences of various handicaps and the possible impact of psychological research on educational services. Stressed in the chapter on sensory processes is research on neonate and infant testing and the substitution of one sense by another. The chapter on visual perception provides information on results of impaired vision and perceptual difficulties and asks to what extent perceptual deficits depend on memory deficits. Diagnostic tools for memory deficits are focused on in the fourth chapter which also includes an evaluation of newer methods of memory research and the author's theory of memory. Described and critiqued in the fifth chapter are four main theoretical approaches to cognition: behavioral, developmental, information-processing, and linguistic approaches. Considered in the chapter on language development are the nature of language learning as a dynamic activity and the biological and social factors which determine language development. Discussed in the next chapter are the contributions of several areas of experimental psychology to help children sustain attention and control impulses. The final chapter centers on the personality and social development of the handicapped child. (DB)

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PSYCHOLOGY AND THE HANDICAPPED CHILD

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FOREWORD

The United States is moved today by a new sense of purpose in relation to the education of handicapped children. We have moved out of an era in which educating handicapped children was thought of as a type of kindly babysitting, a generous impulse. Today, parents and educators are perceiving that handicapped children have a right to an education. In our system, which has promised every American child a free public education, the handicapped must not be excluded.

Simply providing handicapped children with a seat in the classroom, however, is not going to fulfill this commitment to equal educational opportunity. It is clear that a quality education program for handicapped children must begin at the earliest stages of life with intervention and treatment designed to prevent or reduce the effects of the handicapping condition. The task will proceed through schooling and must necessarily involve many services in addition to classroom instruction. We have only begun to concern ourselves with the postschool role of handicapped people, the additional job training, the more effective involvement in community life, in essence, the total involvement in our society.

To bring about these goals the Bureau of Education for the Handicapped is making a conscious effort to involve many disciplines and professions in the joint efforts that will be necessary. Efforts have begun with the National Institute of Mental Health, the American Academy of Pediatrics, with general educators through the Chief State School Officers, with educators through the work of the Office of Child Development and the Head Start program, and through this publication.

Outstanding scientists have herein presented some of their thinking. Our desire and anticipation is that this information will stimulate additional thinking and additional concern for handicapped children in the psychology profession and associated behavioral sciences.

Edwin W. Martin
Associate Commissioner
Bureau of Education
for the Handicapped

PREFACE

Relatively few behavioral scientists have been concerned with problems confronted by handicapped persons. All too often, one group of professionals has provided service to the handicapped and striven to ameliorate their handicapping conditions while a different set of professionals has studied the skills, competencies, and behaviors of nonhandicapped "normal" persons. Experimental psychologists have usually not sought to obtain information concerning the continuum of skills and behaviors across the *total* population. This information gap could be reduced if experimenters would at times seek out as additional subjects children with pertinent handicaps—if, for example, a series of experiments on developmental verbal learning included numbers of mentally retarded youngsters, or if consideration of role identification included children confined to wheel chairs.

There is also need for the skills and knowledge of such specialists as sensory psychologists, cognitive psychologists, or psycholinguists, in projects designed to develop educational procedures and technological devices for handicapped children. Participation by psychologists and other behavioral scientists in these joint ventures is likely to enhance outcomes for handicapped children and also suggest additional topics deserving of attention either in the classroom or in the research laboratory.

This publication is intended to pique the interest of psychologists in problems of handicapped children and to advance mutual cooperation between psychologists and educators of handicapped children. As the authors indicate, there is much information still to be gained and unlimited challenges lie ahead.

Lois L. Elliott
Bureau of Education for the Handicapped

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Part I

INTRODUCTION

by John A. Swets
Bolt, Beranek, and Newman, Inc.

Each of the chapters in this book describes a basic area of psychology and attempts to spell out relations or potential contributions of that area to problems of handicapped children. These chapters were written primarily for students of psychology. The contributors to this book see a need for greater participation by psychologists representing the core areas of their field in research and training related to handicaps. This book should also be of value to teachers and scientists in the field of special education; its secondary purpose is to present new developments in the understanding of basic behavioral processes in a form readily available to those who directly serve the handicapped.

The basic areas of psychology delineated by the editors are sensory processes, perception, memory, cognition, language development, attention, and personality and social development. The authors of these chapters—Carl Sherrick, Ralph Haber, Wayne Wickelgren, Patrick Suppes, Eric Lenneberg and Barbara Long, Virginia Douglas, and Clara and Alfred Baldwin—are likely known to the reader. They were selected more for their expertise in psychology than for their experience with problems of the handicapped. People with both competences are surely rare, and it must be stated now that the authors do not claim both. We are counting on the combination of general intelligence and good will with proficiency in specific areas of psychology to produce a useful contribution.

In this introduction, I briefly describe the handicaps we shall consider, and a rough idea of the number of children afflicted by each, to give some perspective on the nature of the problem. A few pages follow on what sort of impact, or melioration, we might expect from psychological research and training for service. I then give a brief characterization of each chapter, make some comparisons and contrasts, and attempt to distill the key messages of the aggregate. This introduction concludes with mention of some agencies that have supported research projects, special study institutes, undergraduate traineeships, and graduate fellowships, or that might otherwise facilitate contact with problems of the handicapped.

To Set the Problem

There are approximately 6 million handicapped school-age children in the United States. (1) About one-third of them have pronounced organic or functional *speech disorders* that interfere with oral communication. Approximately one-fifth of them are classified as *mentally retarded*, as unable to benefit sufficiently from the standard school program and in need of special services. About 1 million children, a sixth of the total school-age handicapped, are *seriously emotionally disturbed*; a limited ability to control one's own behavior is associated in the latter case with a psychiatric disturbance and no clearly defined organismic cause.

In excess of a half million children suffer from *learning disabilities*. As described in the legislation of the Bureau of Education for the Handicapped, they are "children who have a disorder in one or more of the basic psychological processes involved in understanding or in using language, spoken or written, which disorder may manifest itself in imperfect ability to listen, think, speak, read, write, spell, or do mathematical calculations. Such disorders include such conditions as perceptual handicaps, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia. Such

term does not include children who have learning problems which are primarily the result of visual, hearing, or motor handicaps, or mental retardation, or emotional disturbance, or of environmental disadvantage."(2)

Some 300,000 children are *deaf or hard of hearing*, and about that many are *crippled* or otherwise *health impaired*. On the order of 60,000 are *visually handicapped*. About 40,000 children have *multiple handicaps*.

I hasten to add that my including a description here of just one of these handicap categories must not be taken to mean that the others can be simply characterized. Let it suffice here to recall that patterns of behavior associated with mental retardation may differ markedly from one structural cause to another (cerebral palsy, central nervous system disorders, hydrocephaly, mongolism, maternal infection, etc.), and also among children whose retardation seems to be functionally determined. I would also add that beyond the numbers of school-age children reported here, the Bureau estimates there to be about 1 million handicapped children of preschool age and has placed highest priority on providing educational services to these very young children.

What Can Be Accomplished?

It is difficult or impossible to speak at all precisely about how much or what kind of good would follow greater participation by experimental psychologists in research and training related to handicaps. I'll simply adduce here a few selected research problems, social developments, and service needs to stimulate the reader to think further about the matter.

A very striking recent research finding, albeit a preliminary one, suggests a large effect of environment on mental retardation. Psychologists Rick Heber and Howard Garber at the University of Wisconsin observed that retarded mothers are likely to have retarded children, and tested the idea that it is the way these mothers treat those children that accounts for the sequence. An experimental group of retarded mothers was given special training on homemaking and baby care while their infants were given daily stimulation and training away from home for several years. These children now have IQ's with a mean of about 125, contrasting with the mothers' mean of 75 and with the mean of children in the control group of about 95. Are the experimental children simply test-wise? Will the differences disappear in time? Heber and Garber acknowledge the possibility, but doubt it. Clearly, they have opened up an important research area.(3)

Jerome Kagan reported a similar finding at the winter 1972 meeting of the American Association for the Advancement of Science. He tested Indian children in San Marcos, Guatemala, where the practice is to leave infants alone in their huts during their first year. Though these children give the appearance of being severely retarded at age 1 year—up to 4 months behind middle-class infants in the United States—at age 11 they score as high as middle-class American children on tests of memory, reasoning, and perception. Kagan believes that our schools should be less inclined to give up on slow starters, that they should work with environmentally deprived children in music, art, and public speaking, as well as in reading, writing, and arithmetic, and should especially concern themselves with the child's self-esteem, which is "the No. 1 factor in school success." (4)

How are handicapped persons ordinarily treated outside of the home? German psychologists Gerd Jansen and Otto Esser supply a partial answer based on a recent survey of society's reactions to visible deformities. Many respondents reacted to the sight of deformity with physically evident revulsion—though with increasing age, rejection tends to be replaced by pity. Few wanted to be friends with a deformed person; fewer wanted to marry or adopt one. Most thought that such persons should be kept out of sight in institutions. Some spoke of the merits of euthanasia. Ninety percent of the people interviewed were unsure about how to approach a handicapped person, with little appreciation of whether he might want help, or, if so, of what kind. "As Jansen and Esser see it, the burden—perhaps an impossibly heavy one—is on the victim himself, to let others know how he would like to be treated and to shift attention away from his damaged body and toward the self inside." (5)

That burden is certainly heavy. As Edwin W. Martin, Associate Commissioner of the

Bureau of Education for the Handicapped, has observed: "In Augustan England, it was fashionable for presumably sane people to go to 'Bedlam' Hospital and pay a keeper to tease the 'lunatics' for their amusement. That kind of flagrant torture that was characteristic of the age of bearbaiting is not much condoned today; freak shows and public spectacles are dying out. Most abuses of the handicapped today take place on more subtle levels that have not changed much in the last 300 years." (6) By relating to what they don't have rather than what they do have, by regarding them as incapable of caring about basic rights for themselves, by feeling that they are served out of kindness rather than obligation, as Martin further observes, society compounds the handicapped person's emotional, intellectual, and economic problems.

Society's reaction to handicaps is a timely issue for research and development as county and State governments are becoming markedly less inclined to house the handicapped in institutions, and as State and Federal legislatures and courts are insisting that handicapped children—with emphasis first on the mentally retarded—be integrated into regular school classes. Martin has raised some crucial questions about the school system: Will policymakers continue to believe that educational frills and extras for nonhandicapped children are more important than basic instruction for the handicapped child? Will teachers receive special training and orientation; will they see a moral and economic justification for an increased work load; or will they, as in some past instances, write provisions into their contracts specifying that they need not work with children who are *different?* Will our open classrooms and increased use of programed materials and individually prescribed instruction make it possible for children to proceed at their own rates in school, so that the retarded child need not be singled out? What is involved in the development of special programs of vocational training for the handicapped? How about preschool training for the handicapped? How about continuing education for handicapped adults?

Several school systems have begun to deal in a programmatic, if limited, way with the problems of learning disabilities. In the Lexington, Mass., school system, for example, the number of staff members focusing on such problems has increased from 1 half-time person in 1968 to 6 full-time specialists in 1972, with recommendations for 14 in 1975. At that point they would serve about 250 children, about the 3 percent of the school population estimated to need special help. Another indication of the growing interest in learning disabilities is a recent international conference on the subject in Boston that attracted more than 1,000 educators.

A central problem posed for learning-disability programs is one that the basic areas of psychology ought to contribute to—how to teach reading. In discussing the town's program, my Lexington newspaper reports a claim that 40 percent of all children learn to read practically by themselves; 30 percent succeed with the "look-say" method; 20 percent require a phonic approach; and 10 percent need additional help no matter what method is used initially. This article refers to "some feeling" among educators that the phonic approach generally applied would prevent most reading handicaps from developing. It mentions another "feeling," that a child should be fully competent in motor skills before going on to cognitive skills. Experimental psychologists have recently begun to give some attention to the acquisition of reading skills, as indicated by a collection of symposium papers. (7) In the concluding chapter of that volume George Miller reflects on how far they have left to go.

The basic fields of psychology should also, of course, contribute to the problem of diagnosis of learning disabilities—of difficulties with spelling, writing, and mathematical concepts, as well as with reading—to help separate, for example, motivation and competence factors. A very recent and interesting study "suggests that as many as 25 percent of otherwise normal children suffer from an unrecognized receptive language anomaly that correlates highly with reading difficulties." (8) The anomaly is revealed in a situation in which children watching a television show can choose between natural sound or sound degraded by various levels of speech interference. The 11 of 44 children in the initial study who showed little or no preference for natural sound tended to score lower on standard language listening

tests, and were later identified by their teachers as exactly those with one or another kind of language and reading dysfunction. Subsequent work with a sample of 230 children supports, for "advantaged" communities, the estimate of 25 percent. This work is being carried on by Bernard Friedlander at the University of Hartford and Hans Cohen de Lara at the University of Amsterdam.

I have noticed a tendency lately, with regard to mental retardation as well as learning disabilities, for parent groups to request, and for boards of education to require, diagnosis by more than a single psychologist, indeed by a panel composed also of a special educator, a physician, and a school nurse or counselor. In the case of mental retardation in Massachusetts, the burden is on such a panel to "'prove" why any given child should be isolated from his peers into special classes. It is evident that psychologists will not run out of challenging problems in these areas in the near future. And it would appear that the payoff for good research, and good training for service, is high.

However, a caveat is required. A colleague of mine, Raymond Nickerson, has observed that the emphasis today on integration of handicapped children in the public schools and the tendency to believe that separate facilities are bad in principle are not without their dangers. One of these is the possibility of obscuring the critical need to improve facilities for individuals who are not capable of being integrated into standard programs to any meaningful degree. To deny that there are such individuals serves no purpose but self-delusion. Further, although rehabilitation—or normalization—is an appropriate goal for many handicapped children, it is an unreasonable one for others. What many very severely handicapped children need more than anything else is acceptance—it can be argued that the problem is less one of training them than one of educating society. Unfortunately, society's intolerance of differences seems to be greater, the more apparent and persistent those differences are.

The Chapters That Follow

In the first chapter Carl Sherrick discusses how we may determine human sensory capacities (a) during the prenatal period, (b) in the neonate, and (c) through infancy and childhood. The indicators of capacity considered in each case are unconditioned responses to stimuli, the electroencephalographic (EEG) and evoked potentials, and conditioned responses. Given the importance of early diagnosis and treatment of handicaps, the emphasis is on testing the neonate's capacities.

I think that Sherrick has succeeded admirably in his "intent to synthesize an experimental orientation to the study of the handicapped child by judicious citation of the literature drawn from a variety of research areas." For more than a survey of the literature, this chapter is a critical examination of the several methods now employed in testing and of the problems faced by any method. The chapter also prescribes the comprehensive program of infant testing that is required to refine these methods.

Sherrick points out that an understanding of the facts and methods of experimental sensory psychology has application broader than solely to diagnosis, and proceeds to consider research on prosthetic devices and methods. Here again, although exemplary devices are reviewed, the treatment is mainly critical and heuristic. An interesting line of discussion concerns the demands placed on students, teachers, and innovators when "the helping but foreign hand of technology" is introduced. Systems that attempt substitution for one sense by another receive most of the author's attention, and he considers in detail directions of future research in this area.

Ralph Haber provides a complementary discussion of sensory substitution as he considers various types of impaired vision. This discussion follows his treatment of the basic operations of the visual system, in which he leads us from its neural anatomy, through coding of spatial information, and sensitivity, to pattern acuity.

For Haber, such handicaps as acuity losses, double images, loss of pattern information, and various kinds of insensitivity—which may be related, respectively, to optical distortions, muscle imbalances, cataracts, and loss of function in the retina or higher nervous centers—are relatively easy to study and relatively easy to remedy, either directly or by retraining or substitution. The contrast in this chapter is

with perceptual difficulties that cannot be traced to some specific failure of a system component, and are often related to language and other intellective dysfunction. The second section of the chapter considers rules of organization, space perception, perceptual constancies, and illusions, with extended discussion of developmental aspects. Under the latter heading, the author pursues the line of research stimulated by Senden's finding with cataract patients that discrimination between objects presented successively is more difficult than between objects presented simultaneously, the former depending heavily on learning and memory, on the availability of names and meanings. To what extent do perceptual deficits depend on memory deficits? Many diagnostic tools, Haber tells us, are insensitive to the distinction.

Diagnostic tools for memory deficits are given extensive treatment in our third chapter, by Wayne Wickelgren. In discussing experimental methods for separating the many aspects of memory, he shows how the older designs such as free recall, memory span, serial anticipation learning, and paired associate learning, are supplemented by the newer study-test, probe, and continuous designs. Whereas the older designs tend to confound the three operational phases of a memory experiment—learning, retention, usage—the newer ones permit nearly independent manipulation of these phases. Wickelgren considers in his discussion of methods the special problems faced in studying memory in children, particularly those with verbal handicaps, such as the limitations imposed by the difficulty of the instructions.

Wickelgren proceeds to present a relatively definite and precise theory of memory, admittedly his personal theory, that delineates a host of separate component processes, and so points to different aspects of memory that may be selectively impaired in children with different types of handicaps. He discusses certain patterns of memory deficit that one might expect to be associated with different handicaps, and offers some suggestions about how children with different handicaps might be trained. The handicaps treated include visual, hearing, and speech deficits, learning disabilities, emotional disturbances, and mental retardation.

Theoretical principles of memory are discussed under the headings of coding, dynamics, and retrieval. This is a different organization than the one developed around the three temporal phases mentioned earlier; indeed, coding and dynamics relate to all three temporal phases. Each section treats both the capacity and the strategy aspects of memory, and points up how improved performance could result from removing strategy deficits even though structural, capacity deficits remain. We see, for example, how removing a deficit in the optional strategy process of "chunking," which together with the associative memory process is supposed to underlie concept learning, could enhance the number and value of concepts available for coding new knowledge.

Wickelgren also touches upon the substitution of one modality for another, referring to the use of visual (finger spelling) coding by deaf children for sequential verbal material that normal children encode phonetically. In so doing, he emphasizes again the need for precise diagnosis, observing that a knowledge of modalities used by a particular handicapped child would help determine how to present material to him.

We come next to a consideration of the area of experimental psychology that is central to research on handicaps and service to the handicapped, cognition. Patrick Suppes characterizes and criticizes four main theoretical approaches to cognition—behavioral, developmental, information-processing, and linguistic—and then considers whether or not we are on the verge of a synthesis.

In the behavioral approach, learning theory is applied to mental development, for example, by Estes. Suppes shows how the simple all-or-none conditioning model applies to concept formation in children, and reviews Zeaman and House's application of an extension of this model to retarded children. Relative to handicaps, he recommends a procedure not followed in practice to date; namely, estimation of parameters of the learning models for individual subjects, or for groups of subjects stratified according to mental age.

The developmental approach, dominated by Piaget, has made very considerable progress in describing the sequence of concept development in children, but has not been applied extensively to handicapped children. Suppes advances three reasons for holding reserva-

tions about the viewpoint associated with Piaget, but none of the drawbacks is intrinsic to the approach. With work over time, it could prove highly fruitful in understanding the problems of development in handicapped children.

The essence of the information-processing approach to cognition is a concern with the processing apparatus that appears to be necessary, and with a detailed analysis of the steps a child takes in attaining a concept. Newell and Simon attempt to simulate human information processing in a computer program, and Suppes touches on the strengths and weaknesses of this strategem. Minsky and Papert suggest that formulating and debugging the separate procedures (subroutines) of a larger procedure (program) is the process people follow in solving a conceptual problem, and Suppes illustrates with some of his own work how an analysis along these lines might go. If through research in the years ahead such analyses are made of the tasks handicapped children should master, and of the processes handicapped children follow, they also could contribute substantially to solving practical problems of instruction.

The linguistic approach focuses on what many consider to be the most important part of cognition, the part that is language dependent. The linguist's work on syntax is best represented by Chomsky; the contribution of philosophers and logicians to semantics was mainly by Tarski. As Suppes points out, we should like a detailed account of both the grammar and meaning of speech, and of their development in the speech of young children. He includes in this section a review of some studies of retarded and deaf children. He also picks up again the matter of sensory substitution, considered earlier by Sherrick, Haber, and Wickelgren, as he considers concept formation in deaf children, and the possibility of using sign language to provide the equivalent of verbal instructions.

Because language pervades perception, memory, and cognition, the editors asked Eric Lenneberg to devote a separate chapter to language development. He and Barbara Long responded with a distinct contribution. These authors begin by asking "What is meant by knowing a language?" Central to their answer is an attempt to disabuse us of the notion that the most important components of language are simply labels or "names." Names of objects, or "content words," as well as "function words," are relational; names are only correct relative to circumstances. To know a language is to be able to relate aspects of the environment in particular ways—an object to its use, or to the speaker, or to the listener, or to another object. Language, just like arithmetic, is "a dynamic, computational *activity*." And so, these authors say, tests of language ability should resemble tests of mathematical ability, and not be simple inventories of items that are remembered. They point out that this view of language has similar implications for rehabilitation procedures.

In a second section Lenneberg and Long consider the biological factors that, in interaction with social factors, determine language development. They discuss here data on genetic background, the regulation of language acquisition by maturational processes, and the existence of a sensitive age for language acquisition—if you will, the boundary conditions for management of practical language problems. They condense some observations on the biological foundations of language into a table that shows features of developmental history and behavioral symptoms important for the differential diagnosis of peripheral deafness, mental retardation, childhood psychosis, congenital inarticulation, and acquired aphasia. A final section that surveys recent empirical studies of normal children, through stages of babbling and one-word utterances and two-word utterances and beyond, is included to aid in the assessment of a child's progress.

At this point in the book we move from five chapters on cognition, broadly speaking, to one on conation, from knowing to acting. Virginia Douglas has supplied this chapter, which is counterpoint also in another way: instead of relating a particular area of psychology to several handicaps, it focuses on a single handicap and looks across the several areas of experimental psychology for the tools that will help us understand and treat it. The handicap, a difficulty in sustaining attention and controlling impulses, shows up in children diagnosed as brain damaged, in children with learning disabilities, and in retarded and cul-

turally disadvantaged children. Douglas and her colleagues have worked primarily with children diagnosed as hyperactive, in whom this handicap is seen to permeate and impair functioning in a wide range of learning and social situations.

Douglas shows us how problems with attention and impulse control can be studied by means of choice reaction time, serial reaction, and vigilance tasks; the orienting response in a delayed reaction time task; concept learning in an automated teaching task; Kagan's visual matching task and Witkin's embedded figures test for the cognitive styles, respectively, of reflection-impulsivity and field dependence-independence; the Porteus maze; Sternberg's recognition test; Piaget's story techniques; and so on. Many of the tests that differentiate hyperactive and normal children are also sensitive to stimulant drugs. Some indicate a link between perceptual-motor abilities and attentional problems. The need now is to develop and standardize such measures so that a battery of tests can be used both for diagnostic purposes and for evaluating the effectiveness of treatments and training methods.

The chapter concludes with a discussion of the effects of various training methods (including self-pacing), continuous vs. partial reinforcement, contingent vs. noncontingent reinforcement, and a progression from external to internal control aided by "inner" speech.

The last chapter of this book, by Clara and Alfred Baldwin, is devoted to the personality and social development of the handicapped child. It begins by establishing the importance of social interaction in determining the handicapped child's problems and patterns of coping, to a large extent independent of the particular handicap involved. We are thus prepared to believe that the methods of social science will help us understand handicapped children. Conversely, the authors point out in an aside that I would like to emphasize, application of these methods to handicapped children may benefit social science, because the special problems of the handicapped child may be natural experiments with theoretical relevance to social psychology. An example they give us is the problem of self-esteem.

The second section of the Baldwin's chapter is methodological: it discusses the general problems of describing social interaction and some of the specific methods that have been developed for doing so. The emphasis is on naturalistic situations, which must be investigated if sense is to be made of statistical relationships between variables such as social class and parental attitudes on the one hand, and IQ scores and mental health on the other. These variables are "distant," and mediated by the social interactions of everyday life. Naturalistic research by the Baldwins, for example, has served to alter conceptions about what mediates the living conditions of Harlem and lower IQ scores: the hypothetical picture some investigators had drawn of disorganized homes, impoverished mother-child relationships, and inadequate language resources did not survive direct observation.

The relatively large body of research on interactions in families of schizophrenic patients is reviewed next, and put forth as a model for studying handicaps in general. The particular approach to analysis that had been described by Heider as "naive psychology" is discussed in some detail.

The authors advance the methods of the study of "person perception" in a section on social reactions to handicapped children. They implicate the "halo effect" as underlying the tendency for psychologists and educators to regard the IQ score as a general index of social adaptability, and point up the need to develop an effective, separate test of social adaptability. Since the two variables are far less than perfectly correlated, "obviously both criteria should be employed in deciding on such a drastic action as institutionalization." (9)

The question of segregation arises again in a concluding section on self esteem. The Baldwins' analysis leads them to the view that handicapped children should be integrated as fully as possible in normal social institutions.

The Need To Integrate These Basic Areas

The organization of this book may suggest that the basic areas of psychology can be considered independently as they relate to handicaps—but this is clearly not the case. We need some partitioning to be able to talk about tractable problems, but the parts make up a whole. Indeed, as Haber points out in connection with perception and memory, we may

even have a great deal of difficulty deciding whether a relatively simple problem falls under one heading or another. The handicapped child, we know, is whole; he doesn't know about topical breakdowns such as perception or cognition. Moreover, we are unlikely to find a child with a handicap limited to any one of our topical areas. Douglas' chapter shows clearly how a handicap described in a word can cut across every chapter in this book.

The same need to partition, of course, is what leads to single-word descriptions of handicapping conditions, or to "labeling." Some labels are helpful: the Mongoloid classification says a lot about physical abilities, life expectancy, and so on; similarly, the term rubella tells us something of what to look for. Some labels, on the other hand, hardly offer a clue: among "trainable retarded" children the variance is huge on almost any dimension you might define. One is impressed how much such children differ, for example, socially: how much love they give, how much they demand, to what and how well they attend, how they handle control, and so on. Many public schools recognize the problems that labels present and do not transcribe them in permanent school records. Virginia Douglas and the Baldwins treat this matter of labeling in some detail.

Disentangling our psychological topic areas and our handicap labels is a major challenge. We should learn how to distinguish spillover from a handicap in one area to behavior in another (e.g., deaf children who are classified as retarded because verbal skills play a large role in testing) from genuine cases of multihandicapped children (e.g., children with both visual and auditory handicaps of such severity that they can not be expected to achieve in an educational program designed for children with a single handicapping condition). Douglas cites an instance in which she found no differences between hyperactives and normals in short-term memory, language ability, abstract reasoning, and reading ability, despite the fact that the hyperactives had failed one or more grades and were receiving almost uniformly lower marks. She attributes this surprising result to the fact that her tests were individually administered.

In his first paragraph, Suppes remarks that "it has become increasingly difficult to draw any sharp line between cognition and perception." The line is perhaps fuzziest in the information-processing approach to cognition. The steps one takes in attaining a concept may not be much different in kind from the steps one takes in attaining a percept. Haber introduces his chapter by pointing up the processing on which perception depends: the information in the stimulus feeds into a process that actively synthesizes and constructs a meaningful picture of the physical world. And, of course, many investigators take an information-processing approach to memory. In his section on coding Wickelgren suggests that the formation of concepts results from an associative memory process and a "chunking" process, and discusses the employment of previously established cognitive structure in new learning.

The interdependence of the chapters in this book is further illustrated by the several topics that come up for discussion in more than one of them. I have mentioned sensory substitution in connection with the first four chapters. Douglas, Haber, Wickelgren, and Suppes each has a good deal to say about attention. Sherrick, Wickelgren, and Douglas discuss arousal. Wickelgren and Douglas discuss the possibility of teaching children tactics that may help them overcome deficiencies; the latter author articulates with the Baldwins' concern for social development by imparting such tactics to children with moral immaturity. Haber discusses the rules of visual organizaton and so provides background for Douglas' discussion of field dependence and independence. And so on. I would single out one topic that probably does not come up enough from the point of view of persons who work with handicapped children; namely, motivation. A chapter on this basic area would have been a good addition to this volume.

Of course, not all cross relations among chapter areas were discussed by our authors; an example is the impact of social conditioning on cognitive and memory skills. We are acquainted with the thesis that flooding children's environments with sex-stereotyped stimuli may lead girls to show less in the way of mathematical and mechanical skills than boys. Frederic Charles Bartlett wrote about social factors in recall 40 years ago, and a recent article on chess playing adds to the picture by showing

the effect of practice on selective memory skills. (10) If social forces determine the skill areas that receive practice, then performance related to memory and cognition is likely to be affected. Though perhaps most relevant to economically disadvantaged persons, the point has importance for handicapped children and young adults. Deaf children have traditionally been counseled and prepared to assume jobs as bakers, power-sewing-machine operators, printing press operators, and so forth, and so may have been less likely to develop the skills needed for computer programing or architectural drawing, to name just two fields in which the deaf have recently been performing very well.

Having said that it is necessary to apply the several areas of psychology in coordination, let me move up a level and say that we need to combine psychology and other fields in an interdisciplinary approach to handicaps. A specific example of an attempt at sensory substitution will illustrate both assertions.

In a project sponsored by the Bureau of Education for the Handicapped, a group of psychologists, engineers, computer scientists, and speech scientists at Bolt, Beranek, and Newman, Inc., is working with special educators at the Clarke School for the Deaf to develop a training device to improve the verbal communication skills of the deaf and hard of hearing. Speech sounds of the pupil with hearing loss are directed to a computer—either by means of a microphone and a bank of filters, or by means of a miniature accelerometer that may be taped to the throat to pick up pitch, or to the nose to detect nasalization. The computer immediately feeds back visual representations of any of several aspects of the incoming speech—pitch vs. time, loudness vs. time, presence and timing of voicing or nasalization or aspiration, inferred tongue movement during a vowel, etc.—and provides comparisons with such aspects of the desired form of the utterance. The computer can also produce a tactual representation via a vibrator placed on the pupil's arm or throat. This system can be used additionally to represent the ongoing speech of a teacher directly to a group of deaf students; they can see, and feel at their larynx, for example, which sounds the teacher is voicing, and perhaps learn how to read lips more accurately. One can easily appreciate that sensory, perceptual, memory, cognitive, language, and motivational factors are all always in the forefront during the design and testing of such a system, and that the contributions from disciplines other than psychology are essential. In many instances the appropriate interdisciplinary team would include social workers and physicians. (11)

The Message

What are the key messages of this book for members of the two disciplines, psychology and special education, who particularly constitute its target audiences? The intended messages are that psychologists can do research that is at once "basic" and of potential benefit to the handicapped, and that experimental psychology has something of practical value to say to practitioners of the art of educating or providing services to the handicapped, with the corollary that direct interdisciplinary contact is desirable to enhance the prospects for transferring and applying the results of research.

Clear examples of results of the kind that practitioners can use, it seems to me, are the observations of history and symptoms that Lenneberg and Long present to aid in differential diagnosis, and the observations of infant utterances they present to aid in assessing a child's progress. Other examples are the training methods that Douglas found most effective, and the methods she found undesirable, for use with hyperactive children. Some techniques for diagnosis and for evaluation of treatments that are developed in psychology may not be handled directly by teachers, but are nonetheless techniques they may want to be cognizant of, such as the various measurements of sensory capability discussed by Sherrick, and the descriptions of social interaction discussed by the Baldwins.

It is clearly possible to do basic research with direct positive impact on handicapped children in the field of infant sensory capacity that Sherrick describes, and work on tactual sensitivity especially may have direct implications for prosthesis. Separating component processes in memory, as Wickelgren attempts to do, provides a basis for analyzing, and possibly overcoming through special training, memory deficits of diverse causation. Suppes

shows how detailed study of comprehension provides a practical technique for constructing curriculum, with special reference to deaf students. Many other examples will be found in the following chapters.

I am reminded of the class of research that F. V. Hunt, a physicist, termed "motivated basic research." A professor at Harvard University for about 40 years, to about that many students who took their doctorates with him, he wrote: "The comparison of our fund of knowledge to a great reservoir is hackneyed but useful. Each application constitutes an outlet from this reservoir, and the good applied-researcher knows that there will be less dilution and a lower impedance drop if the 'fuller knowledge' he turns up can be pumped directly into an outlet channel. The basic-researcher with a leaning toward 'purity' is content for his contribution to 'fuller knowledge' to fall anywhere on the reservoir's watershed; but the motivated-basic-researcher has a gleam in his eye and an urge to inject his contribution of 'fuller knowledge' into the reservoir somewhere near the place where application outlets already exist or seem likely to appear." (12) The outlets in the psychology reservoir that lead to handicapped children, I submit, are many and are often nearby.

Whose responsibility is it to ensure that the results of research that could be helpful to practitioners is made readily available for use? The editors of this book believe that the experimental psychologist should accept the major responsibility—as teacher, researcher, and author. Actively "giving psychology away"—by teaching other than psychologists on occasion, by slanting research when the opportunity arises, or by publishing sometimes in a journal of applications—beats waiting for it to be picked up. Some special effort in working directly with a teacher or scientist in the field of special education will increase the chances that the gift is appropriate.

Agencies

A large number of agencies stand ready to help someone who wants to learn more about handicapped children. Some 70 national volunteer agencies, for example, relate in some way to the mentally retarded (such as the National Association for Retarded Citizens), and others concentrate on other handicaps. The Easter Seal Societies, United Cerebral Palsy, and such professional associations as the Council for Exceptional Children and the American Speech and Hearing Association will identify resource people, and may arrange visits to schools, clinics, or residential facilities. Depending on the purpose, contacts might be made with the Director of Special Education in a State's department of education or in a local school district, or with a department of special education or educational psychology at a university. Some agencies provide opportunities to gain more extensive experience through volunteer work or part-time jobs.

Several agencies have provided support for training related to handicaps, for research on problems of the handicapped, and for educational services to the handicapped, including particularly the Bureau of Education for the Handicapped in the U.S. Office of Education. Branches within its divisions of training, research, and educational services are concerned with project centers, or curriculum and media, or aid to States, to name a few special areas, or, in the case of training, with a specific handicap such as communication disorders or learning problems. Other concerned agencies within the U.S. Department of Health, Education, and Welfare are the National Institute of Neurological Diseases and Stroke, the National Institute of Child Health and Human Development, and the Rehabilitation Services Administration.

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Part II

1. SENSORY PROCESSES

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A century ago, an author could still aspire to present an exhaustive account of his field in a single book. Now, one book serves to cover only the narrowest of specialties, and the author of a chapter such as the present one is literally embarrassed with information. It is not my purpose to provide the reader with an encyclopedic account of the sensory psychology of the infant and child: rather, the intent is to synthesize an experimental orientation to the study of the handicapped child by judicious citation of the literature drawn from a variety of research areas.

No attempt will be made to present the fundamental facts of any sensory modality. Several books that are readily available provide admirable coverage at all levels of description, and these will be cited at the appropriate points. Instead, the chapter will outline critically the methods currently employed in the testing, evaluation, and diagnosis of sensory or sensory-motor capacities in neonates, infants, and young children, especially those involving relatively simple stimulus displays and requiring responses of minimal complexity.

The importance of early diagnosis and treatment of handicaps has been repeatdly emphasized by physicians and educators alike, who have found that the prompt introduction of special care and facilities for both child and parents improves the chances of good adjustment to the condition (see, e.g., Elliott & Armbruster, 1967). For this reason, greatest stress will be laid on investigations of sensory processes in the earliest months of life.

[1] The author thanks Dr. E. C. Lechelt, and Profs. F. A. Geldard and P. A. Ornstein for their critical reading of a draft of the chapter, and Miss Claire Kowalski for her editorial assistance.

Understanding of the facts and methods of experimental sensory psychology has broader application than diagnosis, however, and an increasingly important branch of sensory research is concerned with supplemental sensory prosthetic devices and methods. These may serve to enrich the environment of the child or aid in speech or reading training, orientation, or motor coordination. Directions of future research in this area will be considered in some detail in a second division of the chapter.

In an earlier period, one hackneyed phrase in education was "teach the whole child," by which was meant the educator's intent to improve every skill and capacity the maturing youth required for meeting life as an adult. It became the fashion to sneer at the approach that bore that label, but the attitude it expresses is one to bear in mind while reading this chapter. The handicapped child presents his community with a major deficit, such as deafness, blindness, or motor difficulties. If the evaluation of the deficit or its treatment is too narrowly focused on the one modality, other problems may be missed. Only a broad diagnostic and therapeutic program can reduce the likelihood of such occurrences, and stress will be placed on the importance of a multivariate approach to infant testing and treatment.

Sensory Capacities in the Prenatal Period

The results of research on human fetuses removed by surgery for medical reasons may not have direct application to the evaluation of sensory deficit, but they provide one basis for an understanding of the development of the behavioral patterns that appear at birth. The number of investigations in which exemplary methods and measures have been developed is

great, and these merit the most careful study by the researcher.

In this as in other areas, the definition of the subject of investigation is somewhat arbitrary in nature. Eichorn (1970, p. 244) has noted that if a fetus with a weight less than 500 gm (about 5½ months), is delivered and fails to survive, it is commonly termed an abortus. If the weight is more than 500 gm it is termed premature, whether or not it survives.

Unconditioned Reflexes to Stimuli. A detailed history of observations on the behavior of both animal and human fetuses has been given by Carmichael (1970). A briefer account that is confined to human fetal activity is provided by Humphrey (1970), who has stressed the importance of cinematographic analysis for detecting components of reflex responses that may escape the investigator's eye in real-time observations. Whereas early investigations of fetal activity were inconsistent in the completeness of their descriptions of the condition of the specimen, recent studies have carefully noted the general physiological state, the time since removal, the presence of drugs, duration of observations, medium of suspension, temperature, etc. On the other hand, the age of the fetus may be calculated by a number of criteria, of which Carmichael (1970, p. 495) lists six. Investigators have relied on length or weight measures to estimate the level of maturity of their subjects, and the error in this measure reduces the precision of description of behavioral capacities in the prenatal period of rapid maturation.

According to Humphrey (1970, p. 12) the earliest responses to stimulation have been measured in a fetus of length 20.7 mm, and approximately 8 weeks old. Stroking of the mouth region with a hair esthesiometer produced a contraction of the neck muscles on the side opposite the stimulated point. This is described as an "avoiding reaction" (Humphrey, 1970, p. 12). Responses to kinesthetic (muscle stretch) and vestibular stimuli have been demonstrated within 2 weeks of the first tactile response, and so-called spontaneous activity appears in the same period. In general, responsiveness to tactile stimuli appears first in the head region and later in more distal loci, with generalized responses predominating until the 10th or 11th week, when there has been noted sensitivity of the palms and soles, accompanied by limb movements independent of head and trunk responses. At the 16th week of age, the fetus becomes more quiescent and unresponsive to external stimuli, in part owing to a reduced oxygen supply concomitant upon rapid growth, and in part to the growth of higher inhibitory brain centers and their nervous processes.

The senses of vision, audition, smell, and taste have not been sufficiently studied in fetuses to afford an adequate judgment of their status. The majority of cases describing responses to stimulation of these modalities have been premature births. These will be considered with the behavior of neonates.

The sucking response and its modification in the presence of external stimuli have been the subject of extensive investigation (Kaye, 1967; Kessen, Haith, & Salapatek, 1970, pp. 329–339) in neonates and infants, but its instability and weakness in fetal life does not recommend it for systematic study in prenatal work.

Of the autonomic activities available for measure in this period, the fetal heart beat is most notable, beginning at the fourth week (Eichorn, 1970). Recordings of the electrocardiogram (EKG) have been made both *in* and *ex utero*, and a review of techniques and results is given by Eichorn (1970, pp. 203–206). Research in this area has, however, centered around heart action as a gauge of fetal health during gestation and delivery, and although Sontag & Wallace (1936) were able to demonstrate the modification of fetal heart rate by external vibrotactile stimulation, there is little else to suggest that the unconditioned heart rate response has served as an index of fetal sensory capacity.

Electroencephalography (EEG) and Evoked Potentials (EP). A pioneering study of the fetal EEG was reported by Lindsley (1942), who was attempting to record the EKG *in utero* when he noted potentials that appeared to conform to EEG patterns. These were recorded, and when compared to EEG's for the same infant after birth, were found to be nearly the same. The extensive research performed since

Lindsley's study has been reviewed by Ellingson (1967), who has provided as well a clear outline of methods of recording and analysis of the potentials obtained. Recordings *in utero* have usually been made by placing electrodes on the mother's abdomen at points near the head of the fetus, and the consequent attenuation of signals plus the added noise from sources in the mother's body reduce the quality of the EEG. When direct recordings from the scalps of abortuses have been made, it has been pointed out (Eichorn, 1970) that the state of health of the subject is usually in question, and the character of the EEG may be distorted. For these reasons, the major part of the evidence for the patterns of maturation of the EEG has been adduced from investigations of premature babies. This will be discussed in the section on neonates.

The continuous recording of brain electrical activity reveals a great deal about the status of the central nervous system in the infant (see, e.g., Kellaway & Petersen, 1964), but there is little that can be extracted from such records regarding the responsiveness of the organism to controlled stimuli. It is generally agreed that P. Davis (1939) first demonstrated the appearance in the EEG of a transient electrical response to a stimulus, and her work has since been replicated frequently. Only with a few subjects and optimal conditions can the small transient voltages be observed in the continuous EEG, however. As a result, the history of the study of transient evoked potentials of the brain was, for the fourth and fifth decades of this century, a history of inventive methods for the detection of minute signals in noise (Brazier, 1967). With the appearance of the first small general- and special-purpose computers about a decade ago, the difficulties were relieved somewhat, and at present the techniques of evoking clearly defined potentials in specific regions of the brain with visual, auditory, and somesthetic stimuli are being standardized in many laboratories, and some clinics, throughout the world (Bergamini & Bergamasco, 1967; Cobb & Morocutti, 1967; Davis & Silverman, 1970).

The transient electrical response of the brain to a single stimulus may be of the order of a few microvolts, and hence usually unobservable in the presence of ongoing EEG activity. If it is assumed that the same response will appear at a definite time following each presentation of the stimulus, however, and further that the other ongoing activity is random, then the algebraic addition of the evoked transients will increase the size of the desired resultant wave, whereas the wave of ongoing activity will not increase at the same rate. This rule requires that each transient response wave be summated with each other response wave at precisely the same points in time from the beginning of the transient. Therefore, one important element in the recording method has to do with the synchronization or time-locking of the potentials.

In view of the small size of the EP recorded directly from the scalp, it is not surprising that the attenuation of the signals at the mother's abdominal surface, together with the problems of stimulating the fetus *in utero*, have discouraged attempts to record EP's during pregnancy. All reports of developmental studies in babies before term have been confined to premature deliveries (Ellingson, 1967; Graziani & Weitzman, 1971). These will be discussed in the section on neonates.

Conditioned Responses to Stimuli. The best known evidence for prenatal conditioning was reported by Spelt (1948), who conditioned fetal movement to sound by pairing it with a vibrotactile stimulus. Although he observed many of the precautions required for conditioning studies, experts (Kimble, 1961; Stevenson, 1970) have been hesitant to endorse Spelt's findings, particularly in the absence of further studies on the problem. Considering the widespread application of the method to studies of older infants, and to a lesser extent in neonates, one might assume the extension of the methods to the prenatal period, but this has not occurred.

Despite the potentially important theoretical and practical implications of the development of prenatal sensory capacities for neurologists, physiologists, and psychologists, the evidence in the literature of the field is scanty, and cautiously interpreted. The reasons are not difficult to find: if the pregnancy is normal, the measures of fetal behavior are distorted or attenuated by the presence of the mother and the protective tissues that surround the fetus, and

in like manner stimuli are made imprecise. If the fetus must be removed for reasons related to its condition or the mother's health, the normality of the specimen is already suspect. Once removed, the effects of anesthetic or other drugs, the change of temperature, presence of anoxia, and other effects attendant upon delivery of a nonviable organism all contribute to the character of a sample that cannot be considered representative of the population. The improvement of conditions for stimulation and recording of responses is offset by the fact that such manipulations are being made on a rapidly deteriorating organism. The obvious alternative procedure of animal research is unquestionably useful for outlining the major features of development of sensory-motor systems, but the precise mapping of sensory function from one part of the phyletic scale to another is fraught with danger, especially when the organisms in question are studied in the period of their most rapid development.

With the sweeping changes in the laws governing abortion in the United States and the constant improvement in the technology of resuscitation and life support, the sample of available specimens and their condition may be much better than in the past. It is possible that the field of prenatal behavioral research will receive far greater attention in the next decade than at any previous time.

Sensory Capacities of the Neonate

The term neonate is not an exact designation of age, as Pratt (1954, p. 217) has pointed out; the neonate label given the just-born child may stick to him for a period ranging from 1 week to 2 months, depending on the authority quoted. Whatever the criteria for identification, many investigators of neonate behavior have first examined their subjects within a few hours of birth, at a time when the vegetative nervous system is undergoing a most radical modification, and the organism is in a state of severe stress. For premature babies, the stress must be even greater, untimely as the delivery is for the still maturing fetus. Despite these considerations, we insist on knowing what the newborn can sense, whereas our conduct of investigations of the senses of animals and adult humans is guided above all by a kind of rule of organismic equilibrium; i.e., the subject (or observer) must not be disturbed or distracted by other than the stimuli under the experimenter's control. Little wonder if some measures in the neonate should prove to be unreliable! Nonetheless, measures have been taken, and some seem to be replicable.

Unconditioned Responses to Stimuli

Vision. A number of standard texts on the eye, the visual stimulus, and visual perception are available (Geldard, 1972; J. J. Gibson, 1966; C. Graham, 1965). The methods and results to which they give greatest emphasis are those developed with normal adult organisms, of course, whereas neonate sensory research has perforce cast a wider and coarser methodological net to capture its facts. Stimuli for vision have varied from the neurologist's ubiquitous penlight to stroboscopic lamps complete with filter systems, and calibrated in photometric units. Similarly, responses have had broad selection, from the pupillo-constrictive reflex and the electroretinogram (ERG) to measures of general activity. Review of the procedures and results in this area are provided by Pratt (1954), Spears & Hohle (1967), Mussen (1970), and Reese & Lipsitt (1970).

In all but the simplest response measures, e.g., the ERG, it is not just the sensory surface that is being evaluated, but a sensory-motor system. The pupillo-constrictive reflex involves both the optic and oculomotor nerves, and their nuclei. It is observable in the neonate, but the resting size and activity of the pupil is not the same as that of the adult; the response itself is more sluggish; and although the response varies with light intensity, the correlation of pupil size with intensity is not high (Spears & Hohle, 1967, p. 64). Methodological difficulties may have in the past prevented the application of this reflex to the determination of visual thresholds in neonates, but the availability of electronic recording systems should improve the utility and precision of pupillometry for a variety of evaluative purposes (Lowenstein & Lowenfeld, 1958).

The oculomotor responses have been frequently applied in studies of vision and visual perception, as has the ocular-neck reflex. The former are involved in monocular and binocular fixation and tracking of objects in the

visual field; the latter consists of a backward movement of the head in the presence of a sudden increase in light intensity, and is found in premature and full-term neonates (Peiper, 1963). The response of fixation was intensively analyzed in neonates and older infants by Ling (1942), who presented a black disk against an illuminated background to 25 infants ranging from 7 minutes to 24 weeks of age. The subjects were suspended inside a cylinder and observed cinematographically while the object was moved along the line of vision from a distance of 3 inches to a distance of 36 inches from the bridge of the nose. Eye positions and movements, facial expressions, and trunk and limb postural adjustments were all observed and recorded.

Ling concluded, among other things, that there could be defined six stages of sustained fixation, from total absence in the first hours after birth to "post-perfect (roving) fixation (1942, p. 240)" at about 7 weeks of age. The relations of the two eyes in fixation were also developmentally categorized in four steps, from monocular fixation, with the other eye often wandering independently in the least mature infants, to binocular fixation at a median age of 7 weeks, in which, for example, the eyes converge on the approaching object only after some delay, and then spasmodically, with periods of inactivity interspersed. Convergent over compensation may appear at near distances, with crossing of the eyes resulting. Other notable features of Ling's results were the wide range of individual differences in ages at which the stages appeared, and the apparent fusion or even skipping of stages in some infants. Refinements and further applications of Ling's research have been made, notably in the work of Fantz, and of Salapatek and Kessen, reviewed by Reese & Lipsitt (1970, pp. 39–40) and by Spears & Hohle (1967, p. 67). One modification by Dayton, Jones, Steel, & Rose (1964) was the recording of the electrooculogram (EOG) for the detection of small eye movements in the study of visual acuity of infants. Electrodes placed near the inner and outer corners of the eyes will, when the eyes are moved, detect small potential changes that afford an estimate of the degree of eye movement (Alpern, 1962). The EOG has had broad application in clinics for the examination of the central nervous system in adult patients (Bender, 1964) but further research with infants is needed.

The significance of evaluative measures such as the foregoing, especially in research on the handicapped infant, lies in the functional relation of the measure of age, rather than in the status at a single point in time. Repeated measures tell far more about a dynamic system than the isolated test. Put another way, it is not the instantaneous value so much as the trajectory of the function that is of importance to the observer.

There have been a few studies of the response of the autonomic system of neonates to visual stimuli. Steinschneider (1967, p. 21) has pointed out that rapid diminution of the response magnitude with repeated stimulus presentations is a common feature of measures such as heart rate, respiratory, and skin conductance changes. Similarly, general bodily activity changes in the presence of stimuli have shown a tendency to lose their distinctness with repeated presentations. Accordingly, if an evaluative procedure is designed to incorporate these response measures, it would necessarily be brief and simple.

A final innate response measure of visual sensitivity in the neonate is the electroretinogram (ERG). An excellent description of this electrical response of the eye to light can be found in Riggs (1965, pp. 91–98). The human ERG is usually obtained by fitting the eye with a contact lens that has the active electrode attached to it, and detecting the electrical potential of the eye with reference to a second electrode placed on the forehead of the subject. The waveform observed in response to light flashes in the measured eye is complex, and depends on the condition of the eye, the wavelength and intensity of the light, conditions of previous adaptation, etc.

Early reports of the neonatal ERG were guarded or contradictory, but recent studies (e.g., Barnet, Lodge, & Armington, 1965) have shown that by the age of 38 hours, the neonatal ERG is substantially the same in form as that of the adult, although smaller in amplitude by an order of magnitude. The literature contains a number of references to the clinical application of the ERG (e.g., Larson, 1970;

Peckham, 1968, 1969), but no set procedures for infants have been stated.

Auditory Sensitivity. The number of different visual stimuli to which the neonate has been subjected is large, but not when compared to the variety of auditory stimuli he has suffered. If the chorus of bangs, clicks, noises, pops, pure tones, speech sounds, thumps, and whistles presented singly and variously were sounded together, the word cacophony would be forever defined. The acoustician's originally favored sound, the continuous pure tone, produced mechanically by the tuning fork, or electronically by the oscillator and loudspeaker, is often minimally effective as a stimulus for the newborn. With the advent of more sophisticated signal processing and analyzing techniques, the click, and the noise or tone burst have been more frequently applied to research in psychoacoustics. Specification of stimulus parameters has been made more exact as well, as may be seen in the variety of books available on the subject of hearing (e.g., Davis & Silverman, 1970; Geldard, 1972; Jerger, 1963; Myklebust, 1960; Tobias, 1970).

The search for an effective and definable stimulus is not based on pedantry or caprice; it is tied as always to the pursuit of a stable response measure. For the auditory system the attainment of a satisfactory early evaluation of sensitivity is most important. In the other major sense, the visual system, the integrity of the peripheral system may be in some considerable part ascertained by the examiner's visualization of the eye and its internal parts, as well as by integral reflex responses. The ear, however, in the past could not be examined except at its extreme periphery without surgical intervention, and clinical and educational necessity dictated the discovery of good behavioral tests of hearing in the earliest possible period of neonatal life.

There are a number of innate response measures of hearing that are essentially reflexive, but not readily quantified. One of these, which was used to determine threshold for various pure tone frequencies, is the cochlear-palpebral reflex, a closing or blinking of the eyes to a sudden sound. Some authors believe this to be a part of a more general defensive bodily response to startle. One investigator has reported a kind of orienting response of the eyes to sound in a single day-old neonate (Wertheimer, 1961), but other workers have found such responses appearing rarely before 26 weeks of age (Spears & Hohle, 1967, p. 97). The change of general activity of the infant in the presence of sound, applied early to sensory studies by Pratt, Nelson, & Sun (1930), has frequently been a part of the evaluative procedures in the testing of hearing.

Two response measures that have received much attention in the past have been heart rate changes and breathing modifications in the presence of stimuli. The former is discussed at length by Graham & Jackson (1970), who have made a careful analysis of procedures for measuring heart rate changes. These authors report as well a series of experiments directed at the question of the relation of heart rate shifts to the development of general stimulus- and response-processing systems in the neonate and infant. One finding reported by Graham & Jackson has been that, in the neonate, the shift in heart rate is almost invariably upward; i.e., an acceleration, for an auditory signal. This is interpreted by them to be part of a general protective-energizing system, or defensive response, as opposed to a system facilitating information processing, or orienting response which appears more clearly in the older infant. Control by the latter system, these authors suggest, is manifested as a deceleration in heart rate in response to sounds. Changes in depth or rate of respiration have been noted by a few authors (see Steinschneider, 1967, p. 19), but no extensive literature on the subject exists.

Investigators have been tireless in their hunt for an "objective," or "physiological" measure of hearing capacity, and in recent years, three methods have been developed to perform the desired function. One of these, the brain potential evoked by the acoustic stimulus, will be treated in a separate section. A second that is in the early stages of development is the measurement of the intra-aural reflexes to sound stimuli. This procedure, roughly analogous to that of observing the pupillo-constrictive reflex to light, requires the expert application of a device for measuring the change in acoustic impedance of the middle ear (Davis & Silverman, 1970, p. 92) caused

by the action of the ossicular muscles in response to moderately loud sounds. Recent research on children 4 to 11 years of age with the electroacoustic impedance bridge (Brooks, 1971) gives promise of the extension of its application to infants, for the determination of reflex response as well as certain significant static parameters; e.g., compliance, of the middle ear.

A procedure that involves minor surgery under local or general anesthesia, but which offers promise of independent analysis of the function of the cochlear nerve, is called electrocochleography (Portmann & Aran, 1971). A small needle electrode is inserted through an ear speculum and passed through the drum membrane until the bony promontory of the cochlea is contacted. The hole in the drum heals quickly after removal of the needle. Clicks or tone bursts produce electrical potentials between this and a reference electrode on the earlobe. These are processed by a response averaging computer system to eliminate the so-called cochlear microphonic and other unwanted potentials, and reveal the activity of the nerve itself. Threshold values, the wave form of response, and the relation of nerve potential amplitude and latency to sound intensity are all variables that may be studied by this means, in very young infants as well as older children.

Somesthetic Sensitivity. The somesthetic system is generally divided into subgroups having either a common anatomical locus: e.g., the skin senses (touch or pressure, pain, temperature); or a common function, e.g., the proprioceptive senses (kinesthesis, static limb position, the vestibular system). A third grouping—the so-called organic senses, comprising receptors in the viscera and assorted internal organs, and functional categories such as hunger and thirst—is a catch-all for sensory channels that are little understood and rarely studied in infants or adults (see Boring, 1942; Geldard, 1972).

Stimuli for the skin senses may be mechanical; e.g., blunted rods, hair esthesiometers, air puffs, or vibrators. The temperature senses are of course excited by hot or cold metal rods, liquids, air streams, or thermodes, which change temperature when electric currents are passed through them. Cutaneous pain can be produced by sharp pointed objects such as ordinary pins, by hot objects, by some chemicals, or by controlled electrical shocks. The last stimulus is usually regarded as complex, for depending on electrode size and placement and the character of the voltage wave, nearly all the skin sensations perceived can be excited by it. It is commonly supposed that the electrical stimulus bypasses the mechanoreceptors and excites directly the nerves of the skin, but there has been no analysis to determine the pattern of excitation of the peripheral nerves that this form of energy might produce.

The proprioceptive stimuli have in general been mechanical; e.g., passive limb movements, stretching of muscles with reflex hammer blows, changes in body or head position, or rotatory motions about the longitudinal axis of the body. The part of the vestibular system responding to the last-mentioned stimulus is the semicircular canals, and these may also be excited by caloric stimuli; i.e., cold or warm water sprayed by syringe into the external ear canal. The advantage of caloric stimulation is that each side is separately treated, whereas rotation must excite both sides.

When responses are paired with the items of this list of stimuli, much of what results will look like a synopsis of neurological tests. Mention was made earlier, in the discussion of fetal behavior, of the development of reflex responses to skin and proprioceptive stimuli. The newborn exhibits an even greater variety of fairly stereotyped behaviors, but these are shortly lost as maturation proceeds. A clear and complete list of reflexes can be found in Peiper (1963).

The more generalized unconditioned responses of heart rate and breathing changes, as well as skin temperature changes, have been studied in relation to a variety of tactual stimuli, but in general quantification of relationships has not been attempted in the neonate. There have been attempts to quantify the electrotactual sensitivity of the neonate, and observe its variation with age (see Spears & Hohle, 1967, p. 107). The response of limb withdrawal was observed when 2-sec pulsed dc shocks were delivered to it. The results suggested that sensitivity increased over the

first 4 days of life, a conclusion that was supported in part by a later study. It can be stated with some certainty, however, that refinement of measures of sensitivity in the somesthetic area may never equal the precision required by the normal behavioral development of the infant in his natural environment. Crude measures of cutaneous and vestibular sensitivity probably suffice to differentiate normal and deficient cases, for these senses seldom undergo the long apprenticeship of the visual and auditory systems, and therefore are seldom strained to the limits of their information-processing capacities. The kinesthetic system defies testing beyond a certain level of complexity, however, and awaits the proper stage of cerebral and cerebellar maturation for its most subtle trials in its role as steersman of the motor systems. Recognition of this fact is implicit in the outline of most child and developmental psychology texts, in which a separate chapter on motor development is provided (see, e.g., Crowell, 1967; Gesell, 1954).

The Chemical Senses. There are proabably no sensory systems in which the acquisition of new facts has proceeded more rapidly in the last score of years than in taste and smell, thanks to the efforts of a small but growing number of researchers in several parts of the world. The major thrust of the work has been in the areas of stimulus control, anatomy, and electrophysiology with animal subjects (see, e.g., Geldard, 1972; Hayashi, 1967; Pfaffmann, 1969; Zotterman, 1962). Research on human neonates has centered on the response to various odor or taste qualities measured by modification of breathing, heart rate, or general activity, in the case of odor, or changes in sucking rate, facial expression, or general activity for taste stimuli. Difficulties in control of the stimulus, adaptation of the sense channel, and the phenomenon of habituation have combined to make the study of these systems most unwieldy in a program of sensory evaluation, and the progress in the field lies yet in the hands of experts (Reese & Lipsitt, 1970, pp. 56–62; Spears & Hohle, 1967, pp. 99–105). This does not imply that an understanding of the capacities of these systems is unimportant, but until a method of evaluation is provided for integration into a general testing procedure for neonates, the significance of deficits in these channels in relation to other capacities will remain obscure.

The Disruption of Ongoing Responses as a Sensitivity Index. In a simpler age, psychologists tended to think of the organism as a passive system that rested between stimulations like the obedient adult observer in classical psychophysical procedures, and to emit responses when stimulated. Much of the work on innate responses has adopted this approach of looking for responses to stimuli according to the reflexive model of behavior. On the other hand, studies of general bodily activity have frequently reported decreases in "spontaneous" levels in the presence of stimuli (Irwin, 1941; Ling, 1942). It is obvious that, to the observer, a decrease serves the purpose of a signal as well as does an increase in activity. The important question concerns the stability of the response measure.

One such response, that of sucking activity, has received careful study over several decades, and from the first "rooting" response of the neonate on to the inevitable weaning age, the character of the sucking response has been analyzed qualitatively and quantitatively by scores of investigators (see, e.g., Kaye, 1967; Kessen et al., 1970, pp. 329–339). One particularly exciting report from a group of Russian investigators dealt with the successful use of the inhibition or disruption of sucking behavior as a test of sensory capacity in the newborn (Kaye, 1967, pp. 28–35). Within a short time a number of attempts to replicate the original study were made, but only limited success was reported. It appears from the later studies that what had been regarded as effective control of sucking behavior by the sensory stimuli was in fact the result of an adventitious programing of test and control trials. Sucking behavior varies with state, satiety, previous activity, and duration of the period of opportunity, among other things, and when these conditions are controlled among groups the effects of transient environmental stimuli are not observed consistently enough to warrant the application of the method to psychophysical studies. This is not intended as a criticism of the Russian work, but as an example of the precautions needed in analysis of any procedures intended for use in sensory evaluation.

There is no shortage of ideas for ways of gauging the infant's ability to process information; there is a serious lack of concern among researchers for establishing firmly the techniques they have devised, and to place them properly within the context of their application. Investigators must constantly remember that they are dealing with an organism that is maturing at its most accelerated pace, under the stress of rapidly alternating periods of hunger and thirst, sleep and wakefulness, comfort and pain, and handling and isolation. In the midst of this Jamesian "blooming, buzzing confusion," the very latest in research techniques may have little significance for the subject.

The Electroencephalograph and Evoked Potentials

The small electrical potentials that can be recorded from the scalp as either spontaneous rhythms or stimulus-induced transients could be placed under the previous heading as innate or unconditioned activities. Owing to the voluminous literature on the subject, however, and the highly specialized nature of the techniques of measurement, these phenomena deserve separate treatment. There are many books devoted to the topic, but for an excellent introduction to the subject of electrophysiology and normal and some pathological electroencephalograph (EEG) recordings, the work of Brazier (1968) deserves study. More advanced treatment of the EEG in human infants is given by Kellaway & Petersen (1964), by Ellingson (1967), and for prenatal and neonatal animal preparations by Himwich (1970, esp. chaps. 14–16).

The EEG. It is well beyond the scope of this chapter to detail the complex procedures involved in producing records of ongoing brain activity; the reader is referred to Ellingson (1967) for a concise statement of the major aspects of instrumentation and technique.

What is important for the present purpose is the relation of EEG activity to sensory input. One question to be dealt with in more detail later relates to the state of arousal of the infant. It has been mentioned previously that sensory testing procedures are always and inevitably laid upon a background of ongoing activity that is particularly labile in the infant. The EEG has proved to be a reliable and accurate indicator of state, and currently enjoys preeminence in that role for many purposes. A second question concerns the general condition of the infant's nervous system. If a program of testing of infant sensory capacities is seriously contemplated, an important consideration must be the individual differences in levels of maturation of the nervous system, and the EEG along with correlative neuroanatomical studies, is helping to provide a descriptive analysis of the development of brain function (Ellingson, 1967); Ellingson & Rose, 1970). Sufficient evidence is available at present to state some general principles of maturation of the EEG obtained principally from the study of premature babies or abortuses: (a) activity appears toward the end of the first trimester of pregnancy, principally at very low frequencies of 0.2 to 2 per sec, overlaid with low-voltage fast activity at frequencies up to 30 per sec; (b) premature infants of 5 months of conceptional age show bursts of activity at low frequencies with periods of silence interspersed. There is no synchrony of activity. For the duration of the normal term (i.e., 40 weeks) and for a month following, the pattern remains fairly stable. The brief description given is an average for many observations, and large individual differences have been reported in the maturation patterns. Furthermore, the change from one stage of development to another may be quite rapid, and the single observation of an immature pattern in a neonate should not be accepted as prognostic of poor development. Repeated observations of immaturity over weeks is, however, cause for concern. The relation of the potentials observed at various ages to underlying nervous structures is not well established, but the consensus drawn from research with animals is that the potentials are subcortical in origin for the most part.

Evoked Potentials. The ongoing EEG is of use for determining level of maturation, the condition of the nervous system, and the state of arousal of the subject; the analysis of the evoked potential (EP) is intended to yield more specific evidence of the competence of sensory systems. Methods for recording and amplifying EP's are essentially the same as for EEGs, but because the potentials are so

much smaller, special processing techniques are required to reveal their exact form. In addition, the stimuli that elicit the EP's must be controlled as carefully as possible to assure that whatever response variation occurs is attributable to the organism. Responses to visual, auditory, and somesthetic (mainly cutaneous) stimuli have been studied in animals (Himwich, 1970, chaps. 13 and 15), adult humans (Bergamini & Bergamasco, 1967; Cobb & Morcutti, 1967; Perry & Childers, 1969), and infants (Davis & Silverman, 1970; H. Davis, 1972; Ellingson, 1967; Graziani & Weitzman, 1971).

Visual Evoked Potentials (VEP). Interest in the VEP began early and has been maintained at a high level, in great part because some components of the complex wave form have been shown to be specific to activity of the visual area of the cortex (i.e., the occipital lobe). The so-called nonspecific components can be elicited by stimuli to other modalities, or have diffuse representation over the scalp, or are observable as shifts in level of arousal as judged by EEG pattern changes. Ellingson (1967, pp. 83–88) has summarized the general findings for the maturation of the VEP from the second trimester of pregnancy to the first months of life as follows: (a) they are less complex in form than mature human VEP's, (b) they show a longer latency, (c) they are more easily "fatigued" (i.e., decrease in amplitude with repeated stimulation), (d) they are recordable from more restricted portions of the scalp, and (e) like the EEG, VEP's exhibit a range of values over individuals, but not over states of arousal within individuals at normal term birth. The effects of central nervous system (CNS) pathology on the character of VEP's in neonates are not clear at present (Ellingson, 1967, p. 87; Graziani & Weitzman, 1971) and even in normals, individual differences in VEP measures are very large (Ellingson, 1970).

Auditory Evoked Potentials (AEP). Research efforts to define the VEP have a theoretical orientation, and secondarily clinical implication. The AEP has almost from the beginning claimed the attention of clinicians and research workers interested in a dependable early measure of auditory sensitivity (Goldstein, 1963), and the specific application of the evoked potential to the determination of the threshold for hearing at various frequencies is called electric response audiometry (ERA) (Davis & Silverman, 1970; H. Davis, 1972). At present a number of clinics have installed ERA apparatus, and good validation of results has been reported with behavioral audiometric procedures for children of 4 years or older (Davis, Hirsh, Shelnutt, & Bowers, 1967). The pattern of maturation seen in the VEP is not duplicated in the AEP, according to Graziani & Weitzman (1971); whether this is due to the greater proportion of nonspecific components in the AEP is not clear. There is in fact little agreement among investigators about the maturing AEP in prematures and term neonates, except that the amplitude of the wave changes with stimulus intensity, and the wave is unchanged by sleep-waking cycles in neonates under 2 days of age. For purposes of audiometric evaluation, in any case, Davis & Onishi (1969, p. 33) have suggested that infants be tested no earlier than at 2 or 3 weeks of age, to be certain that the middle ear cavities have cleared of the mucous, commonly present at birth, that is suspected of producing a conductive hearing loss. Very likely the delay would insure that a more mature and stable AEP will result as well.

Somesthetic Evoked Potentials (SEP). A number of studies of the SEP have been carried out in adults (Cobb & Morocutti, 1967; Brazier, 1968, chap. 15), but only one or two studies of the neonatal SEP have been found (e.g., Desmedt & Manil, 1970). These investigators selected 34 normal full-term neonates between 26 hours and 6 days of age, and arranged to record and monitor, in addition to the SEP, the EEG, the EOG, respiration, and electromyograms from the submentalis muscle. SEP's were recorded from active electrodes both at the vertex and in that part of the parietal region showing greatest activity for stimulation of the contralateral hand. Stimuli were 0.5 msec electrocutaneous rectangular pulses to the finger of one hand, delivered at a low repetition rate, and at a level that was sufficient to elicit the potential but not so intense that the state of arousal was modified, judged by the measures described above. The resulting

SEP's were stable in appearance, with notable, differences between responses in different states, and no differences in the character of responses between 1 and 6 days of age. H. Davis (1972) has reported the use of SEP and VEP, in cases for which the AEP was either obscure or not obtained, as controls for integrity of the CNS. He suggests as well that the SEP wave aids as a template in examining records for very weak AEP's.

Two reports that may currently be regarded as only laboratory curiosities are nevertheless worth mentioning, not simply to complete the list of the senses, but to indicate the variety of uncharted paths in sensory psychophysiology. There has been a recent investigation of the brain's electrical response to taste stimuli, which the authors claim has yielded evidence for a gustatory evoked potential (Funakoshi & Kawamura, 1971). A second group of investigators, in attempting to record an olfactory evoked potential, have determined that their manipulations of odorous stimuli in normal, anesthetized, and pathological nasal passages have revealed a trigeminal response to olfactory stimuli (Smith, Allison, Goff, & Principato, 1971). Results such as these are indicative of the possibility of additional sensory testing, to afford the researcher and the clinician more and different opportunities to analyze the activities of the infant nervous system.

Conditioned Response Measures of Sensory Capacity

Thus far we have considered those situations in which the neonate has been coaxed to yield up responses that are in his congenital repertoire. To be sure, some are much simpler than others: the pupillo-constrictive reflex does not involve the variety of nervous activities required for fixation and visual tracking of a moving object. Many investigators are not satisfied with the evidence of sensory capacity from the application of congenital reactions, however. They assert that, if a stimulus can be shown first to exert no control over a given response, but that it does so following some specified procedure, then (assuming appropriate control measures have been taken) one can be sure that the organism is sensitive to that stimulus. To continue the previous example: if one can demonstrate that the pupillo-constrictive response occurs to an increase in light intensity, but does not occur with only the passage of regular intervals of time, one can proceed to illuminate the eye at regular intervals, and in a test period observe whether the pupil now constricts in the absence of the light. If it does, we may conclude that the organism can be conditioned to temporal intervals, provided we institute control procedures to ascertain that, for example, irregular illumination changes do not produce the effect, or that the effect vanishes (extinguishes) when no further regular intensity changes occur. The experiment was in fact successfully conducted in the manner described (Brackbill, 1967, p. 237).

Procedures such as that outlined, or even more complex situations that require an instrumental response to a previously ineffective stimulus, are to be regarded as conservative in their estimate of sensory capacities, since if the proper controls were instituted one may safely infer that the sensory system of interest must have been involved. By the same token, the method requires that a far more complex set of systems be intact as well, to effect the process of acquisition of control by the test stimulus. The training methods, as these are called (Warden, Jenkins, & Warner, 1930), are preferred by comparative psychologists in situations that may yield ambiguous results when "natural" responses are permitted. Furthermore, whereas the stimuli for congenital reactions are restricted by their very nature to a small set of known stable stimulus-response relations, the conditioned or learned responses can (theoretically) be placed under the control of any stimuli detectable by the subject.

A search of the literature for investigations in which classical or operant conditioning procedures have been applied to sensory evaluations in prematures and neonates reveals only a few studies yielding reliable results. Reese & Lipsitt (1970, chap. 2) and Brackbill & Koltsova (1967) have summarized the available evidence on the subject. The latter authors conclude that, (a) whereas conditioning is possible in prematures and neonates, trials to condition are greater the younger the infant, and (b) the use of aversive stimuli (e.g.,

electric shock) in conditioning is almost never successful at this age. A major problem, therefore, in conditioning and learning studies in the neonate is one of time. Procedures involving the use of rewards or positive reinforcement generally require time to develop, and the neonate may no longer be at his original level of maturity when he achieves criterion for sensory testing by those methods. Combining this with the fact that the more rapidly acquired conditioned aversive responses have not been successfully applied to these subjects, we are left with the conclusion that, for the neonate, training methods for the study of sensory processes are not a realistic alternative at the present time.

Problems Associated With Neonatal Sensory Evaluation

It is obvious to persons familiar with behavioral research that each method of sensory evaluation must present its own advantages and difficulties; at the same time there exist a number of issues that appear in nearly all the descriptions of method. These may be roughly divided into: (a) problems concerning the state of the organism and the effects of treatment on that state, and (b) problems concerning the sensory function to be analyzed, and the criteria of the experimenter for a significant response. Whereas many early studies recognized the existence of these problems, it is only in recent years that researchers have been able to deal with them constructively in the experimental context.

Problems of State and Its Modification. It has been noted previously that a besetting difficulty in sensory studies of the neonate is the variability of the background activity against which the presentations of stimuli and observations of response are made. Put another way, we may ask how we know the infant is prepared to receive and respond to our signals. The descriptive statements in classical psychophysics ". . . trained *O*'s (or *S*'s) . . . ready signal . . . feedback for responses . . ." are taken to mean that the subjects were normal, they have reached some asymptote for performance, are motivated, prepared for the stimulus program, and receive knowledge of their past performance to maintain their attentiveness to the problem of observing. The question of the state of the adult subject seldom arises; he is usually alert. If he is not, the data for his period of inattentiveness will betray him. Except for sleep studies, the assessment of states in adults is seldom made, with the result that evidence for the effects of state on sensory capacities is lacking. The neonate, on the other hand, is less often alert, and may spend as much as 60 percent of his time in various stages of sleep (Kessen et al., 1970, p. 317). The problem that first presents itself is to determine a set of stable criteria for a stage of alertness, and to ascertain that these are in evidence during periods of stimulus presentation. A more general approach will be to determine, for a given stage, what the responsivity of the infant is, and whether the program of stimulation itself has a significant effect on the state. To the latter problem there should be appended the point that some response measures; e.g., the ERG, do not seem to be affected by state changes. Brackbill & Koltsova (1967, pp. 237–238) noted that during pupillary conditioning the monotonous repetition of stimulation put the infant to sleep, and his eye had to be held open in order to visualize the pupil. Nevertheless, conditioning apparently took place!

The classic monograph of Pratt et al. (1930) contains descriptions of the carefully designed coding system and the stabilimeter for designation of stages of alertness, and in the years following, a number of investigators attempted to refine their system, first by designating levels or stages of alertness that comprised particular behavior patterns, as well as by adding measures of specific activities to the stabilimetric record; e.g., respiration, heart rate, the EEG, eye movements, limb movements, etc. (see e.g., Hutt, Lenard, & Prechtl, 1969, p. 133). At present, a number of state criteria exist; these can be lumped into four descriptive behavioral categories that may be designated quiet sleep, active sleep, quiet awake, and active awake. Two studies that considered the relation of order of states from sleeping to waking with responsiveness to stimuli have shown that the correlation is very poor (Bell & Haaf, 1971; Hutt et al., 1969). The state of highest excitability seems to be active sleep, according to several authors (e.g., Bell & Haaf, 1971; Lamper & Eisdorfer, 1971). This seem-

ing paradox is further complicated by the review of Hutt et al. (1969), who, in a critical analysis of experiments on the concept of state and the measures of arousal, have pointed out that some responses are enhanced in quiet sleep, others in active sleep, others in the active waking state, and some are present in two or more states. These observations are borne out by H. Davis (1972), who suggests that in all cases of recording the AEP care be taken to establish in the child a state of quiet alertness, for which the potential will be maximal. Davis considers a skilled attendant indispensable for this purpose. A second choice of states he accepts, especially for infants, is normal or sedated sleep, in which electrical artifacts produced by movement are eliminated. The work of Graham & Jackson (1970) is pertinent to the question of state and responsibility. In their studies of heart rate change to auditory stimuli, these authors noted that in neonates whose state was not monitored, the stimulus produced on the average an acceleration of heart rate, whereas in neonates who were stimulated only in the waking state there was no significant change in heart rate from that of control trials.

The modification of state of arousal with repeated stimulation has become a multifaceted problem, or to draw a plainer if mythological analogy, a hydra-headed monster. As every elementary psychology student knows, repetitive application of stimulus energy to a sensory surface may produce: (a) peripheral adaptation (receptor failure), (b) nerve accommodation, (c) central adaptation, (d) effector fatigue, (e) habituation, (f) facilitation, and, to complete the multiple choice exercise, (g) all of these or (h) none of these. To this proliferation of physiologic sequelae must be added behavioral observations that some stimuli seem to disrupt activity and arouse the infant, whereas others seem to soothe and sedate him. The avoidance of the difficulties resulting from repeated stimulation has in classical psychophysics been effected by spacing repetitions sufficiently. However, for many purposes this stratagem is not feasible: in acquiring a readable evoked potential, for example, one may require 20 to 60 repetitions of stimuli. If these are spaced less than 1 or 2 sec apart, the potential becomes too small for clear recordings. If the spacing is too great, the trial time may exceed the infant's span of quiescence, and movements can destroy the accumulated record. The dilemma holds for the studies of heart rate, breathing, conditioning, etc. Two studies that have been directed to the question of stimulus effects have concluded that the stimuli they employed (sounds, cold, pressure) did not affect the state of arousal (Hutt et al., 1969; Lamper & Eisdorf, 1971). The stimuli were transient in those studies, but an oft-repeated finding has been that steady stimulation may reduce activity significantly over that for no stimulation (see, e.g., Spears & Hohle, 1967, p. 98; Brackbill, 1971).

Habituation has become the effect of greatest recent concern to psychologists, in part because it has practical application to the design of programs of stimulus presentations, but more importantly for the implications it has for theory in both physiology and psychology. The most complete definition of habituation to date has been given by Thompson & Spencer (1966), who state nine characteristics of the process that differentiate it from adaptation, effector fatigue, etc. These authors elaborate the physiological mechanisms underlying habituation, and suggest, with experimental illustrations, that what has been called dishabituation (i.e., recovery of the response to a previously habituated stimulus in the presence of a second stimulus) should be regarded as a separate process that they name sensitization. In a second paper, Groves & Thompson (1970) have carried forward the theory of and experimental evidence for habituation and sensitization, and introduced the concept of state as a tonic characteristic of the nervous system. This is not to be confused with the state of the organism we have been discussing, for the former is a more molecular description that is rigorously applied to a restricted portion of the nervous structures the authors have investigated, and is postulated to account for, among other things, the fact that habituation does not occur in sleep.

At a more molar theoretical level, habituation has acquired importance as a possible mechanism in perceptual learning. Very crudely put, the reasoning is that habituation is a higher order process characterized by the steady diminution of the response of an or-

ganism to a repeated stimulus pattern. Other stimuli may at the same time acquire potency because they are paired with events that elicit or strengthen the response. With repeated presentations, the dual process produces an enhancement of responses to the reinforced stimuli and simultaneous attenuation of responses to the habituated stimuli. For conditions in which, say, one of two patterns is reinforced, the basis for discrimination is established. Fantz (1966, p. 166) and E. J. Gibson (1969) have suggested that habituation plays an important role in perceptual development, and Kessen et al. (1970, p. 339) have reviewed much of the research in this area.

The importance of habituation to the study of sensory processes in the neonate lies in the role of this mechanism as a harbinger of the more complex processes to appear in the life of the infant. When, for example, does habituation appear; is its absence evidence for cerebral immaturity or pathology; does one modality exhibit habituation sooner than others, or can habituation appear independently in the various modalities? These are questions that have yet to receive clear answers, for as Kessen et al. (1970, p. 342) have pointed out, a large number of studies have been undertaken, but the wide variation in stimuli presented, responses measured, and other factors simultaneously varied makes interpretation difficult. A number of authors have criticized the tendency of some investigators to apply the term freely to situations that may leave other factors uncontrolled. Hutt et al. (1969) have described several experiments in which habituation was supposedly demonstrated, but because changes of the infant's state were uncontrolled, the conclusions must be considered doubtful. What is required is research that controls for variables such as state of arousal and applies the criteria for habituation to the phenomenon of response diminution.

In the first days of life neonates may exhibit a range of values along the scale of arousal. Much of this variance we may attribute to differences in maturity, irritability, or state of health, but there is mounting evidence that the type and strength of anesthetic or other medication given the mother before delivery profoundly affects the state of the infant for a considerable period following birth. The monograph of Bowes, Brackbill, Conway, & Steinschneider (1970) provides rather surprising evidence for the far-reaching effects of certain anesthetics; infants born to mothers given anesthetics, and tested for sensory-motor capacities as late as 4 weeks of age still exhibited some deficits when compared to babies born without anesthetic. If these results are borne out by repeated studies, the variable of obstetric procedure will have to be controlled in future research, as Hutt et al. (1969, p. 165) have already emphasized.

Dimensions of Sensory Function. An important question that has not been considered concerns the aspects of sensory function that must be determined in order best to identify a sensory deficit. The commonest aspect studied has been the absolute threshold of response to stimulation, of course, and the auditory system has most often been examined for this measure, in part because of the ease of physical measurement but more importantly because of the consequences of a deficit. There are many other aspects of sensory function however; e.g., the difference limen (DL) for intensity, the DL for quality (frequency of sound, hue of light, etc.), magnitude functions, DL's for duration, for temporal pattern, and for localization. In addition, the character of the adaptation process, and of the habituation process previously mentioned are logical candidates for investigation. This is not to suggest that every shaft in the sensory psychologist's quiver be launched in a desperate effort to hit the target, but rather that more information than "he does (does not) respond to the stimulus" is needed if any intelligent prediction of later performance is to be made from early measures. It is possible to find distributed through the literature of developmental psychology isolated experiments on each of many of the sensory dimensions and functions listed above; there are, however, no definitive examinations of any of them.

The interest of researchers has all too often been focused not on sensory functions but on the response measure, and the technologies of instrumentation and statistical computation have been strained to extract the last particle of information from the data. With the appearance of the small computer in many labo-

ratories the two technologies have been combined to produce an analyzing demon in the presence of which many psychologists must feel like the sorcerer's apprentice. It is important to keep in mind that the response record and the analysis can never improve upon the test. Foreign psychologists have often remarked on this tendency among Americans (see, e.g., Hutt et al., 1969, p. 166), and their statements should not be dismissed as merely envious.

More and more frequently in recent years there have appeared discussions of problems of response detection. Given a background record of some continuous activity ("noise") and a set of intervals in which a weak response (signal) may occur, how does the investigator decide when a true response occurred, and when the record shows only "noise?" An authoritative handling of the general problem of detection and some specific examples may be found in Green & Swets (1966), and some descriptions of the difficulties and some solutions in the context of sensory evaluation in children are to be found in H. Davis (1972), Goldstein (1963), Hutt et al. (1969), and Weber (1969). Of special interest in this regard is the recent work by Ling, Ling, & Doehring (1970). For some situations specific to infant research the problem may be further complicated by the presence of an attendant or second experimenter who pacifies or observes the infant. Graham & Jackson (1970, p. 104) have reported a control procedure in their experiments on heart rate responses to sound. An observer watched the infant to identify waking states during which the stimuli were to be presented. To avoid the possibility that the observer might begin to select periods during which apparent responses would occur whether or not there were signals, some trials were made with no stimulus present, and a masking noise prevented the observer from discriminating the trials. Obviously, in cases of audiometric measurement a parent or attendant who holds the child to soothe him must not know when the stimuli are presented under any circumstances. For an appreciation of the subtlety of cues in situations of this kind, a careful reading of Pfungst's *Clever Hans* (1965) or Watson's synopsis of Pfungst's investigation (1914, p. 297) is worthwhile.

Sensory Capacities in Infancy and Childhood

With growth and maturation continuing apace through the rather nebulous boundary between the neonatal and infant stages, the most salient feature of the observed normal behavior patterns is their coalescence. The thin skeins of isolatable reflex responses are gathering to form a coherent fabric that assures sustained and directed contact of the infant organism with its environment. Sounds, sights, and touches to which the neonate was only transitorily responsive begin to bring forth at least metastable chains of reactions. Socialization of a primitive sort has begun.

With the increasing complexity of behavior comes the need for different evaluative procedures, and the progression of content of testing devices is away from the simpler congenital reactions toward the learned responses, from reflex to cognition. The latter activity is the province of other chapters on which the present account will not trespass. For certain cases—e.g., the brain-damaged child, or the educable or trainable mentally retarded—it may be necessary to evaluate the simpler sensory functions at an age when more complex methods are generally applied. It is not necessarily merely a matter of testing a 4-year-old handicapped child with the items standardized for the normal 2-year-old; special tests may be needed, for in this field more than any other the Gestalt dictum, "The whole is different from the sum of its parts," holds true. The handicapped child is not a normal child minus a sense channel or a motor function, or minus so many months of mental age. Careful observation of the child in a variety of settings, aided by video tape recording or other cinematographic techniques may be needed to design a test battery suited to his capacities.

Unconditioned Responses to Stimuli

Vision, Audition, etc. It was noted previously that the neonate loses some of his stereotyped responses in the first few weeks after birth. Responses that are retained—e.g., the pupilloconstrictive reflex—undergo some changes in their latency, magnitude, recovery, etc., and exhibit a somewhat smaller dispersion of values for the population. Responses such as the Moro reflex; i.e., the clasping movement of arms and legs in response to loss of support or

loud sounds, fade away in the fourth or fifth month, whereas the startle response pattern begins to appear only after some weeks of postnatal life (Kessen, et al. 1970, p. 313). A detailed account of the maturational changes of congenital responses may be found in Peiper (1963), and several texts and handbooks have described the sequences of perceptual-motor development (see, e.g., Crowell, 1967; Gesell, 1954; Kessen et al. 1970; Stott, 1967). As part of a recently initiated program of study of the effects of neurological damage, Bayley (1965) has reported the results of testing over 1,400 children from various cities in the United States, ranging in age from 1 to 15 months. The bulk of test items are of the sensory-motor type involving; e.g., postural mechanisms, orientation, or visual coordination of limb movements. Despite the great amount of research in this area, the comments of Kessen et al. (1970, p. 306) on the inadequacy of the predictive power of developmental scales are quite accurate; much more remains to be done.

The Electroencephalograph and Evoked Potentials

The EEG in Infancy and Childhood. A number of modifications of the EEG patterns have been noted by Ellingson in his review (1967, pp. 67–72). One notable fact of maturation is the age at which several changes take place; at 3 to 4 months postterm, the occipital region of the skull has in the waking state become the site of regular 4 per sec waves that can be blocked by sensory stimulation. Some investigators think of the wave as precursor of the alpha rhythm, but others insist that alpha must be applied only to the adult frequency of 8 to 12 per sec and found in this region. By the end of the first year, the occipital rhythm may have reached the frequency of the adult pattern, and other regions as well yield patterns similar to those of adults. The EEG in sleep matures over the same 12-month period to a form similar to that of the adult. In prematures and neonates, once the sleeping-waking patterns are distinguishable, two sleeping patterns may be noted. Quiet sleep, characterized by periods of relative inactivity of the EEG interspersed with bursts of potentials, is seen less often than active sleep, in which continuous irregular slow EEG waves are seen. As the infant completes the first year of life, the proportion of time spent in active sleep decreases and that of quiet sleep increases. By the age of 3 to 4 years the active sleep time has fallen to about 20 percent of the total, and varies little thereafter (Ellingson, 1967, p. 70).

Ellingson (1967, p. 81) has summarized the tentative conclusions concerning abnormalities of the infant EEG, noting that in the absence of seizures and other clinical signs, an abnormal EEG is not necessarily prognostic. By the same token, a normal EEG is not alone prognostic of health of the CNS. In the main, repeated examinations and independent test procedures yield the best predictive data here as in other evaluative techniques.

The Evoked Potential. It was mentioned previously that the visual evoked potential (VEP) contained identifiable elements specific to the occipital region. Ellingson (1967, p. 85) has reviewed the studies of maturation of the VEP from birth to 1 year of age, and has shown that the latency of the first major positive wave of the VEP exhibits a steady decrease with increasing age that forms a two-limbed function in a graphic plot. The intersection of the limbs appears at one month of age, and the asymptote of the second limb is approached by 6 to 7 months of age. The regularity and stability of the function would seem to make it a good predictor of conceptual age, but according to Graziani & Weitzman (1971) it is not better than other procedures, although it may be helpful. At present, the authors have said, the VEP cannot offer great promise for diagnosis of CNS damage until more standardized procedures have been applied to the samples studied.

In contrast, the auditory evoked potential (AEP) has been applied with some considerable success to infants and young children by Davis and his associates (Davis & Silverman, 1970; H. Davis, 1972), and by other laboratories and clinics in several countries. In the young child who does not speak, or is uncooperative or unresponsive in conventional audiometry, electric response audiometry may be the ideal solution to the problem of getting hearing thresholds (H. Davis, 1972). At pres-

ent, the method is applied by a number of clinics to a broad sample of handicapped children, including language impaired, Downs syndrome, and autistic children (see, e.g., Graziani & Weitzman, 1971; McCandless, 1967; Taguchi, Goodman, & Brummitt, 1970).

The somatic evoked potential (SEP) has been studied more for its utility as a standard for comparison with the AEP, as was mentioned (see H. Davis, 1972) than for any other diagnostic purpose. If research such as that of Desmedt & Manil (1970) is extended to older infants and young children, the diagnostic significance of some features of the potential may emerge.

Conditioned Response Measures of Sensory Capacity

Classical Conditioning. Much of the literature on classical conditioning of infants and children is of Russian origin, and Brackbill & Koltsova (1967), Brackbill & Fitzgerald (1969), and Kessen et al. (1970) have reviewed both Russian and the increasingly more frequent American contributions. It is generally agreed that by the first or second month the infant can be conditioned with a variety of conditioned stimuli (CS). Among these have been all manner of lights or visual objects, sounds, tactile or kinesthetic stimuli, odors, and tastes. Unconditioned stimuli (UCS's) have been presented to produce reactions such as dilation, eye blinks, head turning, sucking responses, heart rate and breathing changes, etc. The primary interest of nearly all of the studies conducted has not, however, been in the detection or discrimination of the CS, but in the conditioning process itself. The major exception to this generalization is in the area of auditory studies, and the work of several decades is reviewed by Frisina (1963) and Goldstein (1963). The major application of classical conditioning involved the development of a technique for conditioning of the galvanic skin response (also known as the psychogalvanic reaction, or electrodermal response) to an auditory signal by pairing it with electric shock. On test trials the appearance of a skin resistance change to the sound alone was taken as evidence of both conditioning and, in trials in which the sound was attenuated to low levels, hearing. The requirements of the use of shock, which upset the subjects, and of prolonged sessions needed to establish the response and to measure thresholds, coupled with the frequent lack of success with some subjects have combined to make this procedure unpopular with many audiologists, who more and more favor electric response audiometry, or the simple operant conditioning techniques to be described shortly. For almost any program of sensory evaluation one may say that tests that are nondisruptive, brief, and have a low failure rate are the methods of choice. Further, even if by itself a given test were, for example, nondisruptive and dependable, but inordinately lengthy, it might be unacceptable because it demanded precious testing time out of proportion to its contribution to the predictive power of the battery.

Operant Conditioning. Few fields in American psychology have received more attention in the past decades than that of operant conditioning, and none has been attacked more vigorously by critics of all persuasions for its practices and theories, particularly in the area of educational and social control. Whatever the arguments for or against the methods or the theory of their operation, the fact remains that rigorous psychophysical methods have successfully been developed for animals with the aid of operant techniques, for which Stebbins' book (1970) is convincing testimony. The work with children has commonly been in the area of cognitive or perceptual processes, but an early application was made in audiometry' (Frisina, 1963; Davis & Silverman, 1970, p. 238), and several variants of the technique have emerged under the names play audiometry, "peep shows" audiometry, and conditioned orienting responses. In a comparative study of three methods of audiometry, Motta, Facchini, & D'Auria (1970) examined a number of handicapped children including "aphasicoid-dysgnosic," spastic-athetosic, mental retardation, and rubella syndrome diagnoses. The classical galvanic skin response conditioning technique, the peep show method, and the conditioned orienting response method were tested for efficiency in determination of hearing thresholds. The first technique proved disruptive, and the second and third were more successful, with the third method yielding the high-

est percentage of successful cases. Assuming that the proper precautions are taken for control procedures, there is reason to believe that operant techniques can derive more information in the same time, with the services of an attendant skilled in handling children, than can the classical methods. The interjected phrase concerning the attendant cannot be overemphasized; indeed, as a problem area in need of research, the skills and personal characteristics of the technician in charge of state and affect of the examinee should be given the closest scrutiny for the benefit of all evaluative procedures.

Concluding Remarks on Sensory Evaluation

The Problem of Multiple Handicaps. The skills and ingenuity of the clinician or therapist are sufficiently strained when he is presented with a case of a suspected handicapped infant or child for whom the deficit is in a single modality, or involves one body region. For the multiply handicapped, even fewer avenues of control, available in the normal infant, are open to permit an accurate evaluation of the extent of loss of incoming information to the child. There are the more obvious multiple handicaps of the deaf-blind, mentally retarded blind or deaf, brain damage in various grades of severity, or the rarer hereditary disorders such as Hurler's syndrome, in which abnormalities of connective tissue produce far-reaching effects throughout the system.

As more investigations of various samples of the handicapped population proceed, there appears evidence of what may be called secondary handicaps, previously undetected, but present to a significant degree among the samples. Myklebust (1960, pp. 321–330) has reported the results of studies of visual handicaps in deaf children, and has noted that the incidence of visual deficiencies commonly found in most studies has been higher than for an otherwise comparable normal sample. A similar conclusion was reached by Lawson & Schoofs (1971), who in the course of developing a test of visual acuity for a sample of mentally retarded children found a significantly large proportion of visual deficiencies in the group. In his survey of 8,887 blind children having multiple impairments, M. Graham (1968) found 80 percent to be mentally retarded, 39 percent with speech problems, 35 percent with brain damage, and smaller percentages with emotional problems, cerebral palsy, epilepsy, hearing defects, and chronic medical problems. Graham estimates that 15,000 blind children in the United States have multiple impairments, some with two, three, or more handicaps. It is possible that the apparently higher incidence of secondary deficiencies in handicapped individuals results from improper sampling procedures, or difficulties in testing, or from the fact that the insult to the organism is rarely specific to a single subsystem. If the last holds true for a significant number of cases, we may expect that in the future handicaps may be discovered in psychologically important systems for which there are at present few evaluative techniques. Studies of the sensory properties of the lips and oral cavity in normal and handicapped children, for example, are currently revealing evidence of heretofore unnoticed deficits in sensitivity in the latter group (see, e.g., Bosma, 1967, 1969).

The tragedy of the multiply handicapped is compounded by the treatment afforded them when it is directed to the primary handicap alone. The inevitable emotional responses of the child faced with impossible tasks and of the teacher with an unresponsive or seemingly slow child further complicate what is already a difficult situation. The solution to these difficulties must lie in early and complete diagnosis and prompt therapeutic efforts.

Psychometric Methods in Sensory Evaluation An important part of the problem in research on evaluation of sensory processes is the development of diagnostic procedures that can be made available to physicians and, in some cases, parents, and that comprise test items and devices which probe each of the major sense modalities and sensory-motor systems for signs of deficiency. Some of the procedures, outlined in previous sections, are at hand and have been tested for reliability. Others exist but requre refinement or standardization, and still others are undeveloped. What is needed at present is a comprehensive program of infant testing that extracts representative samples from all parts of the country, combined with a standard method of recording parental histories, sibling histories, prenatal

care, obstetric events, and postnatal examinations. Repeated evaluations, with test items scaled progressively, should be made over at least the decade following birth. What is expected in the final analysis is a listing of evaluative procedures and analytic methods that afford the earliest possible diagnosis of handicaps and recommend the application of proper corrective or educational methods. The task is admittedly a monumental one, but it would not be the first time that psychology as a profession was faced with such a demand for time, talent, and cooperation with other professions. Geldard (1952) has recounted the activities of psychologists in the U.S. Army Air Force selection program of World War II, in which, faced with the necessity of predicting from pretraining tests the success of flying crew members, a group of investigators first performed an analysis of the work of each crew member. From the analysis there were developed sets of verbal and perceptual-motor tests designed to predict success in job performance. These were administered at various stations throughout the country by standard procedures to candidates for flight training, some of whom were then advanced to training status regardless of their test scores. Records of performance at various stages of training were analyzed and compared to the pretraining test scores to determine which of the test procedures predicted success in aircrew work, and the battery originally designed was revised in light of the results. A surprising feature of such batteries, as Geldard has noted, is the predictive power of seemingly irrelevant test items, and the reverse, i.e., what appear to be "good" items to the designer contribute nothing to prediction.

Programmatic investigations of the kind described have already been made, or are currently underway. F. Graham and her associates (Graham, 1956; Graham, Matarazzo, & Caldwell, 1956; Graham, Ernhart, Thurston, & Craft, 1962; Corah, Anthony, Painter, Stern & Thurston, 1965) conducted a prospective study of the effects of birth trauma, especially perinatal anoxia, repeatedly testing samples of normal and traumatized infants from birth to the age of 7 years. Although the investigation was confined to a small class of traumatic events, and the early measures of behavior were limited to a few functions, the project stands as a model of clinical-developmental research. One interesting outcome should be cited: the concept of perinatal anoxia, which seemed to be readily diagnosed in the neonate, proved to have diffuse and far-reaching effects as the infants matured. One might conclude in retrospect that a general condition should have such an effect, of course, but it is of some interest that the behavioral tests at different ages were sufficiently sensitive to confirm the hypothesis.

Of more recent origin is the Perinatal Research Project supported by the National Institute of Neurological Diseases and Stroke, and involving nearly a dozen institutions from as many cities throughout the United States. As a part of this project the work of Bayley (1965), mentioned earlier, included samples from these institutions, and involved careful training of test administrators in workshops that were held prior to the main study. The continuation and extension of projects such as this may eventually provide the detailed understanding of brain damage that is needed. Zimet & Fishman (1970, p. 133) have railed against the undiscriminating acceptance by experimenters of traditional medical diagnoses of brain pathology, and Yates (1966, pp. 120, 134) has pointed out the continuing need for reliable tests and external criteria for such general diagnoses as "minimal brain damage."

The difficulties of specifying the consequences of early brain damage are readily understood if it is remembered that the organism is maturing and recovering from insult at the same time. In a recent review of research on recovery from brain damage, Rosner (1970) has discussed the results of the increasing number of research papers in the area of perinatal and infant brain damage. What may surprise many readers new to the problem area is the consistent finding that the earlier in life the lesion is made, the better the recovery of function as determined by behavioral tests. This agrees with the results of Jilek (1970, p. 359), who subjected rats to anoxia, and found not only that the younger animals survived the trauma in greater numbers, but showed better performance in conditioning tasks than animals treated in the adult stage. In view of the importance of pretreatment and posttreatment

training and environments, and posttreatment training procedures (Rosner, pp. 569–575) it will be interesting to see what interactions may take place among these factors and maturational level (and species) in determining recovery from brain injury. The importance of such research for diagnosis and treatment of the brain-damaged child cannot be overemphasized.

Metastatic Systems for the Handicapped

Since prehistoric times man has extended his senses and done his work with the aid of other men, or animals, or objects he calls tools. Devices that are designed to aid the handicapped are usually referred to as prostheses, literally additions to the body. Canes, glasses, and hearing aids fall in this category. When a prosthetic device is designed to accept information normally conveyed to one modality, but adapts and transmits the information to another modality, let us call it and its user a metastatic system, i.e., a system in which one part or organ of the body takes up the function of another. Glasses and hearing aids, therefore, do not form metastatic systems, because they receive and transit in the same modality code. The cane, however, as used by the blind is part of a metastatic system, for features normally detected by optical information are revealed by the probe cane as auditory and tactile-kinesthetic information for the guidance of the user.

Exemplary Metastatic Systems. There are many familiar prosthetic or metastatic devices and methods in existence at present, and most readers are acquainted with their general principles. The braille system for the blind, speech reading for the deaf, finger spelling for the blind-deaf, the hand-to-face "listening" method made famous by Helen Keller, the manual alphabet and sign language of the deaf, and the guide dog for the blind are all well-known supplementary sensory aids. Artificial limbs for making locomotion and object manipulation possible are prosthetic devices usually classed as motor aids, but their control and effective use depend heavily on the reorganization of the interplay of kinesthetic, tactile, and postural mechanisms. Nearly all of these devices and methods originated in or prior to the 19th century, and evolved from the invention or development of a single educator or physician to their present status of widespread and expert application. The evolution of the methods may indeed be compared to the development of spoken or written language—i.e., they underwent metamorphosis through continual interchanges between pupils, teachers, and inventors, in some cases for generations of handicapped students of high intelligence and motivation. The histories of braille (Farrell, 1950) and of speech reading (O'Neill & Oyer, 1961, chap. 2) are excellent examples of the process of development of metastatic systems. Whereas speech reading began as a teaching art at least as early as the 16th century, and continued as an individually acquired skill until the application of cinematography to teaching and testing in 1915, braille was devised as an alternative printed medium in about 1829 amidst a controversy over the proper character of embossed type for the blind. The influence of external technological developments never ceased to alter, often with stormy consequences, the form, teaching methods, and even publishing practices of braille materials to the present day (Farrell, 1950, p. 325; Nolan & Kederis, 1969; Foulke & Warm, 1967).

The difference between other metastatic systems and braille in ease of acceptance and relative smoothness of development very likely is owing to the greater complexity of the braille method. Besides requiring the student to learn to process a somewhat arbitrary and occasionally modified tactile code, the braille method involves learning to operate a hand embossing device (in which the writing is done in reverse of the direction of reading) or learning to use the braille writer, which embosses the characters, spaces, and registers or indexes the material much like a typewriter. If one considers that in each of these tasks there was introduced on occasion, to students and teachers alike, the helping but foreign hand of technology, he may guess that the complicated process of communicating among professions must have added to the educational problems already present. It will come as no surprise, therefore, that of the scores of methods and devices that have been invented to aid the handicapped, only a handful have ever reached the classroom or the field for a truly compre-

hensive and fair test of their potential as sensory aids. It is the fashion in engineering circles to speak of the problems of man-machine systems; i.e., the design of mechanical-electronic devices and displays to optimize their usefulness to the operator. The problem extends beyond the single organism-machine interface, however; the inventor must convince and instruct the teacher (not just the school supervisor), who must then instruct the student. Moreover, the inventor, not being omniscient, must revise his system in light of students' difficulties with the machine, assuming he has been able to provide accompanying tests to tell him of real progress and where the difficulties lie. The challenge to the inventor of an educational device is Herculean in its proportions, for he is not just handing over possession of an instrument; he is endeavoring to change lifelong habits of teaching and learning (his own, perhaps, included), which in James's words are "the enormous fly-wheel of society, its most precious conservative agent." (James, 1890, p. 121.)

It would be impossible to list the variety of devices that have been developed to aid the handicapped child and adult, but there are available several recent reviews or published symposia on the subject. The history of development of various aids to the blind may be found in Zahl (1950), and more recent accounts of such devices in Clark (1963) and Bliss (1970). These include guidance devices to permit the blind to move and orient themselves in- and out-of-doors, and reading devices to allow them to get information from ordinary books or newspapers. Devices designed to improve speech in the deaf and hard of hearing are described by Pickett (1968) and Keidel (1968). A system for providing kinesthetic and postural cues for the control of prosthetic devices by amputees has been reported by Mann & Reimers (1970), and there has been demonstrated a unique system for engraving a tactile image on the back of the blind user with the aid of hundreds of points vibrating under the control of a modified television camera (Collins, 1970).

Evaluation of Sensory Aids. Although it is worth noting that many of the devices described in these reports involve the tactile-kinesthetic system directly, the fact should not surprise anyone familiar with the senses. As Geldard (1970) has pointed out, the sense of touch lies between the major senses of vision and audition in its ability to process spatial information (better than audition, poorer than vision) and temporal information (better than vision, poorer than audition); it is, so to speak, the least common denominator of the sensory domain. In the evaluation of sensory aids that recruit the skin, or for that matter any other sense, the problem of the man-machine system falls in part in the province of cognition or learning. For the sensory student, however, three important questions demand consideration. First, are the physical dimensions accepted by the device all those processed by the sense that is being replaced? Second, are the dimensions transmitted to the replacing sense modality, all and only those it is capable of analyzing? Third, because sensory modalities never work in isolation of one another, as J. J. Gibson (1966) has so carefully documented, does the metastatic system act in harmony with other modalities as did the lost sense?

Let us take a simple device to exemplify the analysis of systems by these questions. The probe cane of the blind is one such system that is still in use in many parts of the world (Hoover, 1950). The first question, concerning the reception by the cane of all the physical dimensions impinging on the eye, can be answered easily: no, the cane accepts only a small fraction of the dimensions processed by the eye. As ordinarily used, the probe cane is moved slowly back and forth in front of the subject, who proceeds haltingly but with an alert postural (listening?) attitude. He may tap the cane on the ground and shuffle his feet noisily to produce useful sound cues. The important features of his path are impediments or discontinuities—e.g., steps, curbs, holes, and obstacles such as doors, gates, other people, etc. The important events for continued locomotion are the null cue for empty space above the path, and the cue of path continuity. These cues have correlated optical properties, of course, but except for the unusual case in which a seeing man follows an unfamiliar path in the dark with only a pencil-thin flashlight beam to light the way, the sighted person gains many more fea-

tures at a glance over his frontal field of view. The cane accepts a very restricted set of features within only a specified space, and requires that it be thoroughly explored, almost point-for-point, to verify tactually that the way is clear. Additional properties of the frontal space are acquired by the auditory system. Ambient sounds tell the experienced listener something of his environment, and the character of self-generated sounds reflected from objects provides crude information concerning the presence of walls, trees, nearby obstacles, etc. The auditory cues provide fore- and middle-ground information about obstacles; the tactile cues provide foreground information about obstacles and imminent discontinuities, so that one may move about in relative security. Without previous experience and the knowledge of auditory or tactile landmarks however, the blind cannot direct their movements, and can go either where the path takes them or to the nearest point of reorientation, i.e., a landmark or a helpful bystander. The optical features of the fore-, middle-, and background that we take for granted, but that provide our general orientation, are lacking for the cane.

The answer to the second question, concerning the dimensions presented to the replacing modality, is also no. The contact with the environment afforded by the cane is a succession of punctate experiences from which the user must forge a concept of continuous space having a volume limited by the radius of his extended probe. If he had several canes projecting into his frontal field at various angles, he would gain a more rapid and complete assessment of his imminent path. A number of studies (e.g., Bliss, 1970; Geldard & Sherrick, 1965; Gilson, 1969) have shown that multiple inputs to the skin can be perceived and discriminated as patterns, and there is evidence suggesting that the capacities of the skin may be exploited far more extensively than they have been up to the present (e.g., Alles, 1970; von Bekesy, 1967; Sherrick, 1970; White, 1970). The porcupine-like array of canes is ludicrous, of course, but an array of transmitters of sonic, ultrasonic, or electromagnetic energy coupled with receivers of reflected energy (a sonar or radar system) would be more acceptable and perhaps equally as useful to the blind. Guidance devices of this kind exist in the form of a hand-held "flashlight" system (Clark, 1963), but no multiple-array systems have been extensively tested in the field.

To the third question concerning the compatibility and cooperation between the metastatic system and other modalities, one must ask whether it is enough that the metastatic system does not interfere with normal activities of the remaining senses or whether the new system be keyed into their activities to provide for redundancy or for novel transformations of environmental features by repatterning the sensory inputs. If J. J. Gibson (1966) is correct in his assertions, the latter process may occur during use provided there is no conflict of cues. We are left with the admonition to avoid negative transfer and promote positive transfer of learning in the design of such systems. For the probe cane, there seems to be no question of the transfer of learning; no situations have come to light to suggest that it hinders mobility training. Its major faults lie in the paucity of cues it provides the bearer, and the stigma attached to its presence.

It is here proposed that some metastatic systems bear analysis of the kind suggested to insure that they fulfill the functon for which they were designed. For example, if a speech analyzing aid is designed to improve the intelligibility of the speech of the deaf, we may ask what features of the speaker's utterances should be processed by the analyzer? The obvious answer is the airborne sound energy transduced by a microphone and represented eventually say as patterns of skin vibration. If we assume that the aid is a training device that the deaf speaker will not use continually, but only to form proper motor speech patterns, we must point out that airborne cues will be available only during training, whereas oral-facial tactile and kinesthetic cues must suffice at other times. It may be more appropriate to provide electronic correlates of the oral-facial cues in addition to or in place of the sound cues, in the belief that the proximal stimulus patterns controlling vocal effort are in the oral-facial region, and these must be enhanced for the student before he can readily discriminate them.[2] The word "belief" in the last sentence is emphasized,

[2] Dr. J. Kirman, personal communication, August 1969.

for there is little evidence to suggest in what way the various patterns of auditory, kinesthetic, and tactile stimuli share the control of speech in normals or handicapped persons (Bosma, 1967, 1969; Ringel & Steer, 1963).

Developmental Aspects of Metastic Systems. In a provocative analysis of psychological problems of designing sensory aids, Lashley (1950) referred to the products of the then-budding technology of electronic aids to the blind as toys. He pointed out, however, that "the value of toys in stimulating interest, in giving pleasure, and in teaching the properties of objects should not be underestimated" (1950, p. 510). Perhaps Lashley was recalling the work of Birch (1945), in which young chimpanzees who, when tested for tool-using behavior with sticks, initially showed little of the skill in retrieving objects that Köhler's animals had so dramatically exhibited. After 3 days of free use of the sticks, all the young chimpanzees were handling them in a most dexterous manner as extensions of their arms. It is appropriate in the present context to emphasize that almost no research on sensory aids has been conducted in the developmental framework; the opportunities and the means for such work exist now, and the possible results are simply incalculable. If the word "enrichment," which rolls so easily from the tongues of writers, educators, and parents means anything, it should specify the improvement of the quantity and quality of the child's contacts with and manipulation of his environment, in play and social as well as formal educational settings.

The emphasis on the development of metastatic systems in play and social situations should be marked, for as Skinner (1953) once noted, "In an American school if you ask for the salt in good French, you get an A. In France you get the salt." (P. 402.) It is perhaps owing to an earlier thwarting of the present author's research plans that the conviction of this statement is retained. About a decade ago Joseph Rosenstein and the author wrote a research proposal outlining a possible application of closed-circuit television to the improvement of speech in deaf children. The plan was to place TV monitors in various parts of the school, and require the children to obtain information about classes, meals, the time, or local activities, from an announcer in a central station. The announcer could hear but not see the children, and the children could of course only see the face of the announcer. They must therefore apply their speech-reading skills and their oral skills, which they exercised mostly in classroom work, and minimally in social contacts, to get their questions answered. The possibilities for development of this "toy" are far greater than this summary suggests, but as fond as we were of the idea, we convinced few others of its merits, perhaps because we were a little ahead of both the educational and electronic sophistication of the time, perhaps because we shortly thereafter left the unique setting in which the work was conceived.

Conclusions

It was not the author's intention in writing this chapter to delineate a sphere of expertise, lay claim to it, and advertise its superiority over all others in psychology. To the contrary, the lesson to be learned in the sciences is that the truth does not flow from a single bright source like the sun: it emanates from thousands of less brilliant points like stars, with an occasional nova appearing to excite and awe us earth-bound creatures. It may seem at times that the isolation of the branches of science is as great as that of the stars, but it is the single vantage point of the observer that brings them together in their function to guide him on his way, provided he has learned their characteristics well. For the completion of the education of the specialist in a field of science there is no better system than one that puts him in contact with workers in areas distant from his own. One situation in which such cross-fertilization occurs is the problem-oriented research program; e.g., the early diagnosis and treatment of the handicapped child. Emphasis has already been given to the importance of large-scale efforts in the development, standardization, and validation of diagnostic techniques in this field; it should be stressed as well that no single field of study comprises all the skills that would be required to complete the work. Indeed, the full range of knowledge in psychology is insufficient; medicine, biology, the computer sciences, and engineering must play important roles. In the day-to-day planning and execution of his spe-

cial research project, the scientist contributes to the understanding of basic research problems in his field. His additional effort to grasp the overall picture of the research program fulfills his obligation both to transmit and comprehend the meaning of the scientific enterprise of which his work is a part.

If there is a sociology of science, as distinct from a philosophy of science, we may call upon it to tell us under what conditions great scientific enterprises take place. Do they arise only in times of crisis, as did the testing programs of World Wars I and II, or the Manhattan Project of the Second World War, or the U.S. space program of the late 1950's? Or can the Federal agencies, having over the past two decades underwritten much of the cost of development of laboratories and training of graduate students in schools across the country, now lay some claim to the time of its beneficiaries for devising a new approach to the solution of problems such as those of the handicapped? It is not possible to specify the procedures that should be followed to prosecute the various problems that beset all levels of society, but it seems obvious that a single university cannot meet the challenge of the task. What is needed is a consortium of schools, hospitals, and clinics to divide the work and provide the breadth of sampling required for realistic assessment of the problems and solutions.

As it is with living organisms, so must it be with ideas. Conception is the beginning, but months of careful nourishment are required to produce a mature and viable product. The brief contacts between workers in research and development and educators afforded by meetings, conferences, and workshops are good beginnings, but are not enough to foster the development of easy communication among groups, nor the skill in handling the devices, methods, or the jargon of the various professions. From the nuclear physicist we have borrowed the concept of critical mass to express the need for minimal size of a productive research group. We should remember as well that the mass aggregate must persist for a critical time for an effective reaction to take place.

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2. VISUAL PERCEPTION

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My goal in preparing this chapter is to provide a general overview of some of the more important topics on visual perception. Obviously, many topics have had to be omitted; only by doing so can I avoid writing a book instead of a chapter (see, for example, Haber and Hershenson, 1973). In addition, since my goal includes relevant discussion of how perceptual processes relate to, cause, or help understand various types of perceptual handicaps, I can neither cover all topics in perception, nor all types of handicaps, nor even all of those closely allied to perceptual functioning and dysfunctioning.

This chapter has several major subdivisions. In the first some of the basic operations of the visual system are presented, including its neural anatomy, coding of spatial information, sensitivity to stimulation, and visual acuity. In the second, I will discuss some of the failures of these processes, which result in various types of attenuated or impaired vision. The third section focuses on perceptual organization—seeing objects in space. Included here are some notions about the developmental course of this organized perception, as well as some comments about how perceptual handicaps might stem from organizational breakdown. The fourth section will be on attentional processes and their role in normal and handicapped functioning. The last section will include some observations on the perceptual components of reading, and some selected reading handicaps.

Introduction

The study of perception concerns how we come to experience and know the environment around us. As such, perception provides the link between information about the outside world as it impinges on our sense organs and our immediate awareness, knowledge, and understanding of that world. If you cannot perceive anything, you will not be able to know anything either.

At first glance one might expect a chapter on visual perception to cover the physical principles of how the brain receives copies from our sense organs about the physical world around us. But the process is not that simple. Vision does not work like a camera—the eye does not take a picture which the brain looks at. An examination of the neural connections between the eye and the brain shows the impossibility of transmitting copies of the pattern of stimulation reaching the eye. Further, a simple optical examination of the eye will also show how poor a facsimile that pattern is to the world around us. And yet our senses do seem to provide quite precise information and impressions of this world—at least most of the time. And our brain seems to have processes which can extract that information into meaningful perceptual experiences.

For much of the history of experimental psychology—and perception is the oldest topic in that history—researchers have been looking for ways in which copies of the world are represented in the brain, and thereby become directly available as perceptual experience. This quest seemed not only a reasonable one, but to many scientists the only one, since how else could we experience and know the world? But it was a misguided search, since we now know that neither the optics, nor the anatomy, nor the neurology of the visual system (or of any other sensory system) is capable of making faithful or even reasonable copies available to the brain. The brain does receive information about stimulation that reaches the receptors, but it has to synthesize and construct from that the meaningfulness that we impart to the world. This is very different from merely recognizing the world as a faithful copy. In this sense, the interplay between the information in the stimulus and the construction of perception is the concern of the present chapter. To understand this interplay is to understand perception.

This chapter is almost exclusively concerned with visual perception. Vision is our most important and most used sensory system. Nearly all of our spatial information of the world of

people and things is communicated to us via our eyes. While our ears usually provide more precise knowledge of temporal and sequential relationships than our eyes, our eyes are still a major source of spatial information, as well as what comes after what, especially about how fast and in what direction events occur.

Basic Operations of the Visual System

Physical Analysis of Visual Stimulation. To understand how the visual system functions, a brief introduction to the early stages of processing information is needed.

Light is electromagnetic radiation to which the photoreceptors in the eye are sensitive. This radiation can be specified by its wavelength, varying from X-rays and cosmic rays at the shortest to radio and TV waves as nearly the longest. The visible spectrum of radiation is a very narrow range from 400 to 700 millionths of a meter in wavelength.

The eye cannot yield a sensation of light to any other wavelengths. Infrared rays are *felt* by the body's heat receptors as warm, even though they are unseen. No other wavelengths produce any immediate sensory experience, though of course there may be long-term effects from overexposure to the very short wavelengths (X-rays, for example). In addition to the wavelength, light varies in intensity—the amount of physical energy reaching the eye. One of the simplest devices for measuring this energy is the photographer's light meter, which specifies the amount of energy reaching the photoreceptor unit from the direction in which it is pointed. The visual system is capable of responding to an incredibly large range of intensities, as shown in figure 1. Thus, the amount of energy in the light surrounding us on a very bright clear day is 10 trillion times more intense than the minimum amount of light that can be seen in otherwise total darkness.

Radiant photic energy is emitted from a light source such as the sun or a light bulb, but most of the light entering the eye is reflected from the surfaces of objects and backgrounds. The intensity and wavelength of this reflected light is determined by the nature of the source and the nature of the reflecting surface. The colored appearance of the surface is determined by the wavelengths of light reflected from it. A "blue" object appears blue because it reflects predominantly short wavelengths, absorbing a greater proportion of long ones which happen to fall on it. Since most light sources emit a full range of wavelengths, the colored appearance of surfaces depends primarily upon the reflecting qualities of the surfaces themselves.

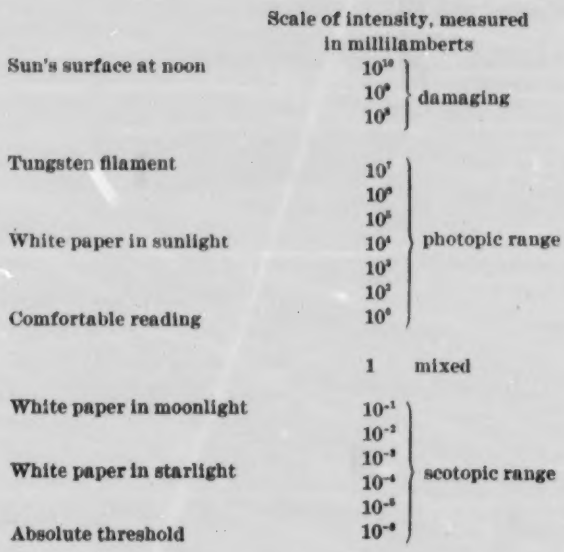


Figure 1.—The range of energy to which the eye can respond. The units are millilamberts, which is a measure of the amount of light reflected from a surface to the eye.

Obviously, if all surfaces reflected light of the same intensity and wavelength uniformly, we would see a world of homogeneous appearance, unbroken by any contour or gradients. But most reflecting surfaces are uneven, so that the reflected light reaching the eye is patterned—varying in intensity and wavelength. This pattern of energy reflected from the surface can be visualized by drawing lines or rays from every point on the surface to the eye, as is shown in the left side of figure 2. This array passes through the cornea and lens of the eye and is focused on the photosensitive retina at the back of the eye. This intensity and wavelength distribution of light on the retinal surface is referred to as the retinal projection of the visual world in front of us. It is this retinal projection which we must consider as the source of information about the visual world.

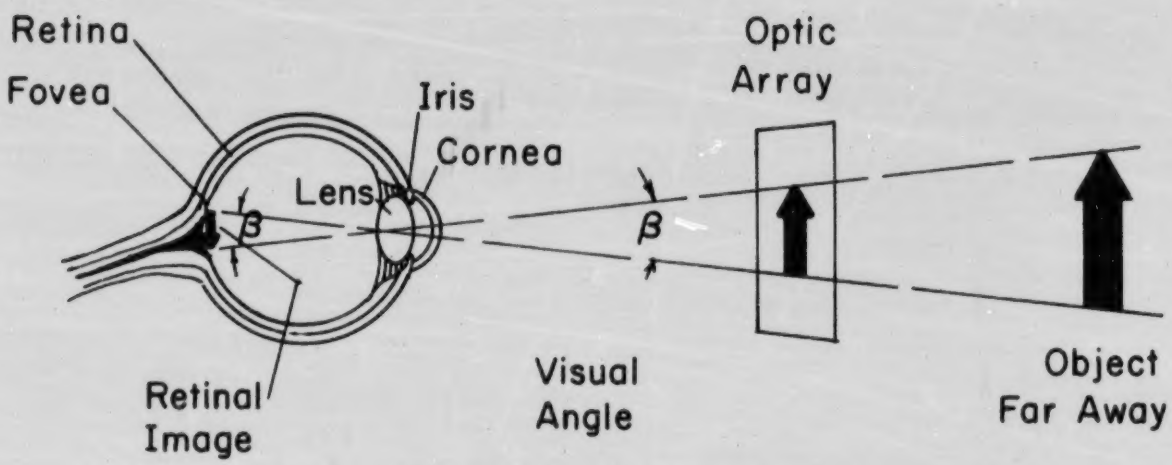


Figure 2.—A retinal projection reaching an eye. The optic array is illustrated by lines representing light coming from the end points of the object, passing through the cornea and lens, and being focused on the retina. Notice that the lens inverts the image. The size of the object in the retinal projection is given by the angle it subtends (β) on the retina, where Tan β = S/D. To provide a sharp focus on the retina, the lens has to change its curvature or accommodation, being thicker for near objects and thinner for far ones. Inserting a plane between an object and the eye illustrates the optic array, the two-dimensional distribution of light energy entering the eye.

The focusing is a result of refraction of the light in the retinal projection primarily by the cornea, which is fixed in shape, and the lens, whose shape can be changed by the contraction of the muscles that surround it. Thus, as the distance of the object from the eye changes, the lens can change in shape to keep as sharp an image as possible on the retina. This process is called *accommodation*. Although the neural mechanisms are not fully understood yet, apparently the brain signals for changes in the lens muscles wherever there is a blurred image on the retina.

Normally, each eye will be oriented so that the center of the retinal projection will be focused on the fovea, the area of the retina with the densest packing of receptors which can thereby produce the greatest resolution of fine detail. This orientation is accomplished by three sets of eye muscles for each eye, which are synchronized to produce this *convergence* of the two eyes.

Visual Receptors and the Visual Nervous System. The right side of figure 2 shows a side view, cross section of the human eye. The photoreceptors embedded in the retina number over 120 million. There are two types called rods and cones by their shapes, although their functions differ even more. The rod receptors are found throughout the retina, except for the very center of the fovea. They are hypersensitive to light energy. A rod can probably begin to respond when a single quantum of light energy falls upon it, which is the indivisibly minimum amount of energy. The rods are especially useful in detecting small amounts of energy, such as in night vision. If you have ever tried to see a very dim star at night you may have noticed that it is easier to do so if you look slightly to one side of the star. This avoids focusing on it with the fovea, which is deficient in rods and hence not as sensitive to low amounts of energy.

The cone photoreceptors on the other hand, are not nearly as sensitive. Each requires large amounts of energy before it can begin to respond. Further, the cones are specialized so that each responds only to a narrow band of wavelengths. Thus, only with cones can we experience different colors. The cones are the only receptors located in the center of the fovea, although they are distributed throughout the retina as well. There are only about 7 million cones altogether.

Figure 3 shows the neural interconnections between receptors and the visual projection areas of the cortex. Both the rod and the cone cells are connected to bipolar cells and these

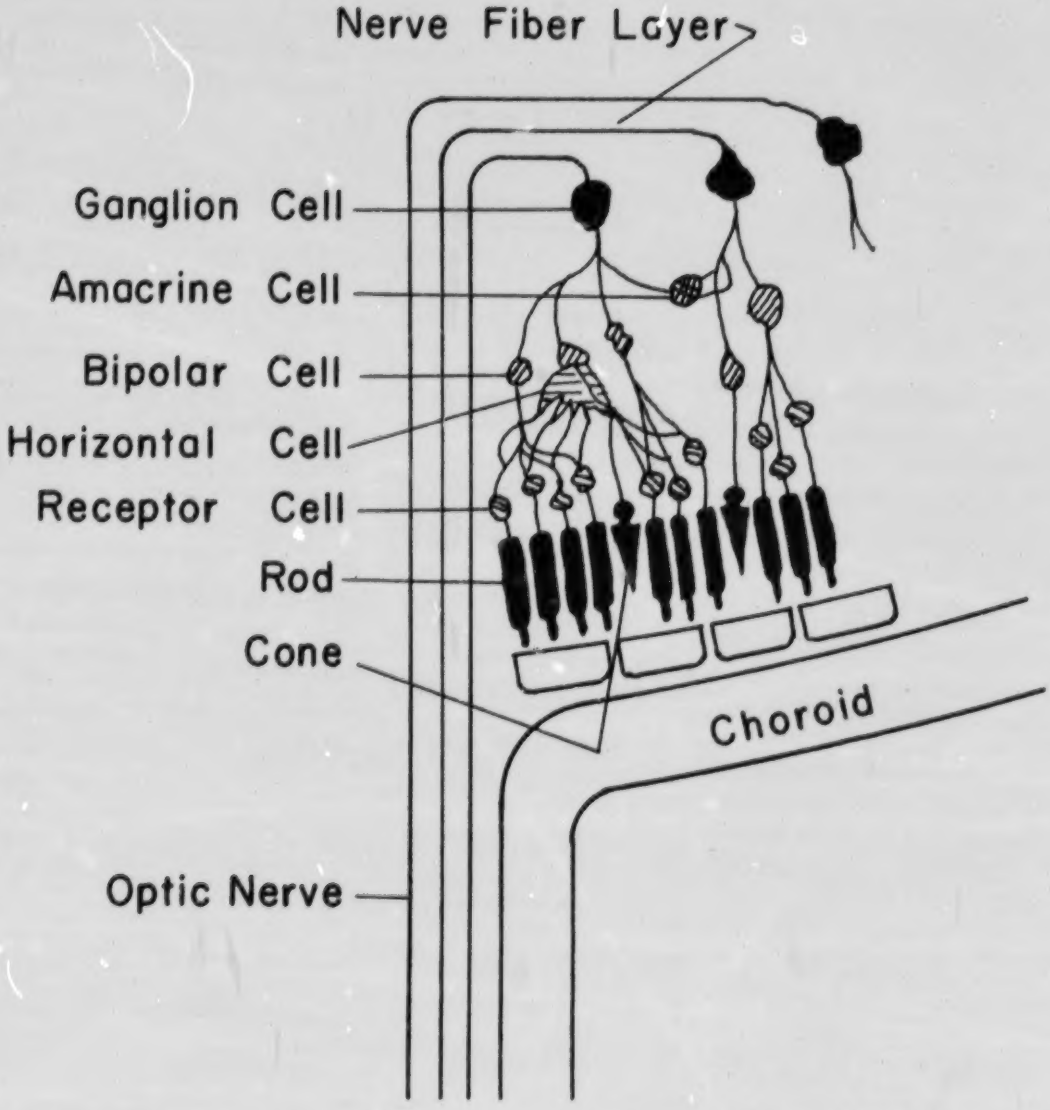


Figure 3.—The photoreceptors and their neural interconnections within the retina. The rods and cones are the two types of photoreceptors located at the back of the retina. Each photoreceptor is connected to one or more bipolar cells which are in turn connected to one or more ganglion cells. These form the optic nerve. Horizontal and amacrine cells also interconnect between and among the bipolar and ganglion cells.

in turn to ganglion cells, whose elongated bodies form the optic nerve fibers which exit the eye through the blind spot (so called because there are no receptors there). The optic nerve fibers connect via a relay station at the thalamus to the visual cortex. But the interconnections are not very systematic—upwards of 100 rods can connect to one bipolar cell, which in turn may connect to a number of ganglion cells. Further horizontal and amacrine cells interconnect between the bipolar cells. It is from these kinds of interconnections that it is impossible to think of the eye as sending anything like a copy of the pattern in the optic array to the brain.

This is not quite as true about the patterns falling on the fovea. The cones have fewer interconnections between the retina and the cor-

tex, and they are much more densely packed. Thus, the ability to resolve fine detail—called visual acuity—is greatest in the fovea, assuming, of course, that the light is not too dim. But as will be evident in a moment, even in the fovea the transmission of fine detail is not due primarily to the specific interconnections of one cone to one corresponding cortical cell. There is still far too much interconnection and blurring to be as simple as this.

The Detection of Visual Features. With the anatomical discovery of the large and divergent interconnections between receptors and neurons in the retina and those in the brain, any kind of straight-forward copy theory of vision had to be discouraged. But this does not mean that interconnections are necessarily random, nor that some quite specific information could not be transmitted to the brain about patterns in the optic array. In fact, the system that appears to be used is more efficient than even a photographic copy theory would have predicted.

If a microelectrode is used to record the activity level of a single cortical neuron in the visual projection area of the brain, then it is possible to learn about the functional interconnections between the receptors and the cortex. This can be done by trying to find what kinds of patterns in the retinal projection are capable of exciting the cortical cell being measured. This, in fact, is now a commonly used procedure in animals from frogs to chimpanzees. As some of the species studied have visual systems very similar to man, we are now beginning to become confident of understanding what happens in man.

The most important pioneers in this work have been Hubel and Wiesel (e.g., 1962). Their goal was to determine the nature of the pattern in the retinal projection of the stimulus that is necessary and sufficient to activate any particular cortical cell in the visual projection area. There are millions of such cells, and Hubel and Wiesel have never been able to sample more than 100 from any particular animal. However, they and others have been able to make important generalizations from even these small samples.

There are two principal conclusions. First, an individual cortical cell is sensitive to patterns in the retinal projection covering an area of a retina much larger than a single retinal receptor. These areas are called receptive fields. A particular cortical cell will have a corresponding receptive field on the retinal surface. Receptive fields vary in size from less than a degree (smaller than the half moon on your thumbnail seen at arm's length), to cover over 10 degrees (the distance between your spread thumb and little finger seen at arm's length). The large receptive fields are more likely to be found outside of the fovea. Receptive fields overlap greatly so that the same retinal receptor may be a member of many different receptive fields.

Second, and far more important, there is great specificity about the kind of patterns in the retinal projection falling on a receptive field that will excite its corresponding cortical cell. Some so-called simple receptive fields will produce a response in the cortex only from a narrow line. Others require that the line be at a 45° orientation (relative to the head); 30° or 60° would produce no response. Others require that the line be at 45° and moving horizontally across the receptive field; and others even specify the velocity of that movement.

The importance of these findings is that there are neural coding mechanisms that permit stimulus patterns to be encoded into a single visual feature represented by the activation of a single cell in the brain. The retinal projection of that pattern may affect millions of receptors, but the brain needs only one cell to represent their activity. Obviously, there have to be many receptive fields for the many visual features in the retinal projection falling over the entire retinal surface, but the principle is the same, and the economy over a one-to-one correspondence system is enormous. Further, this coding is automatically accomplished simply by the neural interconnections.

Some recent research on kittens (Wiesel and Hubel, 1965; Hirsch and Spinelli, 1971) suggests that specific visual experience early in life may affect the kinds of receptive field organizations that develop. Hence, if only one eye is used at a time, so no binocular perception is permitted, then no receptive fields sensitive to stimulation from both eyes will be found. Similarly, if goggles are worn by the kittens that are covered with vertical stripes, fewer

receptive fields are found later for horizontally oriented visual features. Freeman, Mitchell, and Millodat (1972) report results with somewhat comparable implications for humans. Much more work will obviously need to be done on the developmental implications of these neural coding processes, but it seems plausible, in light of the above findings, that severe visual function loss in early life may structurally alter the visual nervous system, so that certain types of visual features are not economically processed.

The number of different visual features which appear to be extracted by the receptive field organization is quite small. The presence of a contour of a line is basic. Its width, its orientation, and its velocity are also specified as features. The location on the retina is given by the location of the receptive field, since fields for the same properties are found throughout the retina. It is possible that receptive fields may have narrow limits for intensity as well. Wavelength appears to be coded as a visual feature, as is any disparity in stimulation between the two eyes.

Even so, the number of visual features comprises a very short list. While the brain may receive visual features quite economically, these features are still a long way from "looking like" the stimulus or even the pattern in the retinal projection. A moment's reflection should indicate that "looking like" is by no means necessary. The lens of the eye already inverts the visual world but that would "look" right side up.

A sense of familiarity as well as the experience of seeing what things look like has to consist of a construction of more complex representations beyond the simple ones based upon the visual features. It is this imposition of an *organization* that is at the core of the science of perception. From three lines of a certain orientation, width, and color, we see them joined at their ends as a triangle. This construction begins from this very short list of visual features. But before examining construction processes, we need to consider the sensitivity of the visual system to light intensity, and fine detail.

Sensitivity to Visual Stimulation. How dim can a light be and still be seen? How fine can a pattern be and be noticed or differentiated from another one? These questions are often of great practical significance, but to provide answers for them we have also learned a great amount about the functioning of the visual system.

The simple detection of the presence of stimulation without regard for its identification would seem to be exclusively a matter of the sensitivity of the visual system and it is for some cases. Very careful measurements under *idealized* conditions have shown that a single rod receptor would be capable of responding to the absorption only a single quantum of photic energy—the minimum unit of all radiant energy. This makes the visual receptor the most sensitive measuring instrument known, far more than anything we have been able to build—equivalent to detecting the presence of a lighted match on an absolutely dark but clear night at a distance of over 100 miles.

But in actual practice we cannot see that well. Idealized conditions do not normally exist. First, even in an absolutely dark room in the absence of any radiant energy, there is a substantial amount of spontaneous neural activity in the visual system. The cortex is continually being bombarded with excitation. Thus, while a single quantum might excite a single receptor, the fate of that excitation would surely be lost in all of the "noise" of the system and would be ignored. Further, while we have talked about a single quantum being absorbed by a photo receptor, it takes hundreds of quanta entering the eye to guarantee that one would be absorbed by a receptor and excite it. Most of the quanta would be lost by reflection off the surface of the cornea, many are absorbed by the fluids and substances through which the light has to pass, many are scattered all over the inside of the eye by errors of refraction in the cornea, lens, and the other substances in the eye, and may fall between the receptors or enter the receptors at such an angle as to be ineffective. Finally, the rods are at their maximum level of sensitivity only if they have been in total darkness for at least half an hour prior to the stimulation.

Of all of these factors the two most important, because they are variable, are the state of dark adaptation and the amount of noise. Dark adaptation refers to the increase in sensitivity

of the photoreceptors with the time they remain in the dark, that is, in the absence of stimulation. It is similar in principle to the refractory period of any neural unit, but it also involves the regeneration of the photopigment in the receptor when light energy strikes it. Nearly everyone is familiar with what happens when entering a movie theatre from a bright street—you cannot see anything at first; the eye is very insensitive. After a short time you can see the screen, then gradually other relatively brighter objects and finally the people around you. Figure 4 shows the time course of such adaptation or increase in sensitivity as measured more precisely in the laboratory. But the results would be the same as that shown in a movie theatre. Persons having to work in the dark generally prepare for this by wearing dark glasses prior to going out into the dark. This begins the dark adaptation period earlier so that they do not need to wait as long to reach full sensitivity outside. Further, since the rods are responsible for the greatest sensitivity to the dark, and the rods are particularly insensitive to red light, if the dark glasses are red in color, you can still see in red light with your cones even though the rods undergo dark adaptation. Thus, soldiers on patrol at night who have to occasionally consult a chart do so while wearing red goggles. In this way they can see the chart without at the same time being temporarily blinded when going back into darkness.

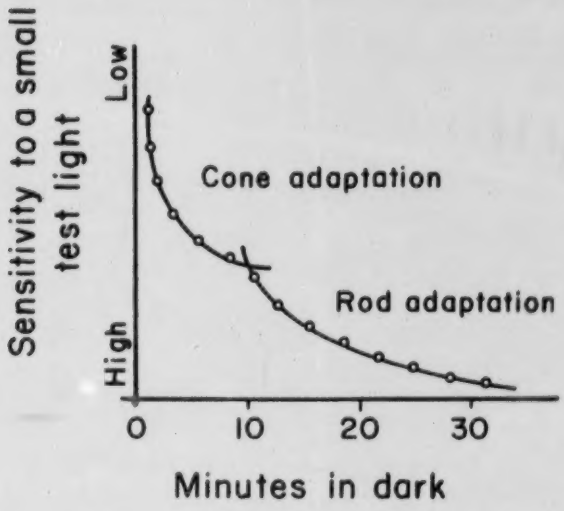


Figure 4.—Changes in sensitivity of the eye to light as a function of adaptation to darkness. Sensitivity is measured by determining how intense a small test spot of light has to be to be detected. An increase in sensitivity is indicated because the test spot can be made dimmer and dimmer and yet be detected, as a result of the length of time the eye remains in the dark. The rapid initial increase in sensitivity is due to the dark adaptation of the cone receptors. There is a further increase of the sensitivity of the rods, which can respond to much smaller amounts of energy. It was evidence of the two sections of the sensitivity function that convinced visual scientists that there must be two kinds of receptors in the retina, even before they found them anatomically. (Taken from Hecht, 1934.)

Roughly the reverse of dark adaptation happens when one leaves the dark theatre to go into the light. The eyes are overly sensitive relative to the high levels of illumination on the street. The iris will automatically contract to cut down the amount of light entering the eye, but this change is very small relative to the change in the amount of light. When this is insufficient you have to squint or even shut your eyes for a few seconds. This loss of sensitivity caused by light adaptation generally occurs much more rapidly than dark adaptation, so that most of the change is over in a few seconds.

As can be seen from figure 4, the sensitivity of the eye to light which the eye is adapted to normal room illumination (about 10 to 50 millilamberts) is rather poor. Thus, in the typical environment light energy has to be very high indeed, for adequate detection of light, compared to the greatest possible sensitivity under idealized conditions.

The second limit on sensitivity is the presence of random "noise." Deciding whether a neural impulse is caused by a stimulus or by spontaneous "noise" activity of the nervous system is of central importance in perception. This is true for the scientist trying to understand the processes and for the perceiver trying to make decisions about the world around him. Swets (1961) provides a full discussion of this point. What it implies is that one cannot talk about a threshold of sensitivity—an amount of energy below which we can never respond, and above which will always elicit a response. Some receptors will respond to any measurable stimulus (and even to amounts too slight to be detected by measurement), and all

receptors respond some of the time even in the absence of outside radiant energy. Thus, rather than talking about thresholds of sensitivity it often makes more sense to talk about a criterion of confidence against which to evaluate the neural response observed at any given moment. Was the response sufficient for me to have confidence that noise alone could not have caused it? In those tasks requiring a simple detection response to dim stimuli, the perceiver is comparing the difference between what he observed and his criterion. Only when the neural response he observes exceeds this criterion will he say that a stimulus caused it. If he relaxes his criterion, then the observation he previously called noise might now be called a stimulus and he will respond. There is no improvement in his sensitivity—only a change in his criterion. That this is so is shown by the fact that when he relaxes his criterion then he will report the presence of the stimulus more often when in fact a stimulus had been presented (a "hit" in signal detection terminology), but he is also more likely to say that the stimulus was there when only noise gave rise to the observation (called a false alarm). If there had been a genuine change in sensitivity (such as would be produced after a period of dark adaptation), then the hit rate would increase without a corresponding increase in the false alarm rate. The critical point to note in this discussion is that one can never talk about the sensitivity of the system without including provision for the criteria for responding. This is true for simple detection problems as it is for the more complex ones—such as "Is that man smiling at me?"

Virtually no work has been done with how confidence might vary in a perceiver with a perceptual handicap. It seems reasonable that such a handicap or a learning disability, emotional disturbance or retardation might affect the criteria one used to decide whether stimulation occurred or not. This is certainly an area for further work.

Pattern Acuity. So far we have been talking about sensitivity to minimal amounts of energy. Acuity refers to the perceiver's ability to notice fine detail in a patterned stimulus. How small can the print on the page be? How far away can we read which direction the arrow is pointing on a curve-warning road sign? How big would a 100-mile high earth-orbiting satellite have to be to be seen with the naked eye from earth? These are all questions which concern the minimum size of detail that can be resolved.

The fovea, with its high density of cone receptors and relatively direct interconnections between receptors and cortex, is specialized for dealing with fine acuity. The convergence of the two eyes will normally bring the center of the retinal projection to focus on the fovea of each eye. Thus, when you are looking at and fixating an object, it is being seen primarily with the foveas of each eye. Since the cones are not as sensitive as the rods to low energy, acuity will naturally be rather poor in low illumination.

Once illumination level is above that needed to bring the cones into play, the major determinant of acuity is the optical resolving power of the eye. This is determined by the ability of the lens to focus the retinal projection sharply on the retina and not in front of or behind it, which would produce a blurred retinal image. When the lens fails to focus accurately, this can usually be corrected with an additional lens placed in front of the eye—the familiar glasses that over two-thirds of the population do or should wear. The standard clinical tests for the need for glasses are acuity tests, which measure how fine a pattern can be resolved or discriminated. Thus, the narrower the line you can see, or the smaller the type that you can read, the better your acuity. Clinical acuity measures are expressed against a standard of 1/60 of a degree of visual angle resolution—being able to accurately read letters drawn with lines 1/60 of a degree wide, at say, 20 feet viewing distance would be 0.07 inches wide. If you have 20/20 vision, then that means that you can just read letters drawn with 1/60° lines if you stand 20 feet from them. Acuity of 20/10 is much better, meaning that lines that would be 1/60° wide at 10 feet you can see at 20 feet. Conversely, 20/100 would mean that lines that would be 1/60° wide at 100 feet you must stand at 20 feet to see. Many States define legal blindness as 20/400. Knowing your clinical visual acuity score, one can determine his minimum visual

angle that he can resolve, as in the above example.

What determines the minimum size of detail that can be resolved, assuming the best possible focus on the retina? Helmholtz, a hundred years ago, proposed that to notice the presence of a line, that line would have to stimulate a row of receptors, and leave those on either side unstimulated. Thus, the minimum resolution would be given by the density of the receptor mosaic of cells—which are, of course, most closely packed in the fovea. The diameter of a foveal cone is about .002 millimeters, which is just over 1/180 of a degree of visual angle. This would imply that letters with a minimum line width of 1/180 of a degree could be recognized. In practice, this is about the lower limit of acuity for the recognition of this type of acuity target. But it is possible to detect the presence of a single fine line whose width is 1/7200 of a degree, or about 1/50 of the diameter of a cone. This is equivalent to a one-eighth inch telephone wire seen against a bright sky over a mile away. Even with eye movements and with blurring, Helmholtz's hypothesis would seem to be only part of the story. More importantly, visual acuity appears to depend upon a brightness discrimination—the lines of cones stimulated by the wire need have only 1 percent less energy falling on them than the adjacent cones in order for the wire to be seen. It is likely that all visual acuity is based upon this type of intensity differential between adjacent cones and not at all upon having stimulated and unstimulated cones adjacent to each other, as Helmholtz thought. In this way, the detail could be far smaller than the diameter of a cone as long as it produced a slight difference in brightness, as a slightly darker wire would against an otherwise intense surface.

Summary. Up to this point we have briefly examined the structure of the visual system and from that considered how information in the optic array can be transmitted to the visual projection areas of the cortex. The recent discovery of the receptive field organization of the retina linked to specific cortical cells provides a system in which patterned information can be represented economically as a set of visual features in the brain. The minimum sensitivity of the visual system to small amounts of light energy has been shown to be primarily a function of the dark adaptation of the receptors in the retina. The detection response to the presence of light is also determined by the confidence of the perceiver that the observation did not result from noise in the system. Finally, sensitivity to fine detail or visual acuity has been shown to be a function primarily of the accuracy of focusing of the optic array on the retina. Pattern acuity seems to arise from an incredibly fine brightness discrimination possible between the energy falling on adjacent photoreceptors.

Visual Dysfunction

Let's pause briefly at this point and look at some aspects of the breakdown of normal perceptual processes. The one which affects the largest number of people is poor visual acuity. Upwards of 75 percent of all Americans wear or should wear glasses. Nearly all of this loss of function is caused by poor optical properties of the eyes themselves. A general consequence of aging is a change in the shape of the eyeball, so that objects near to us are focused in front of the retinal surface, rather than sharply on it. This produces a blurred retinal image with the resultant loss of sharp visual acuity, just as occurs when the lens of a slide projector is not focused for the proper depth of field. Thus, with age, most people become progressively more farsighted, so that distant objects still can be focused sharply, but not near ones. An extra lens placed in front of the eyes can correct this rather easily, although as the shape change continues, the prescription for the glasses needs to be changed with it.

In addition to distortion in the shape of the eye, usually caused by improper balance among the muscles surrounding the eyeball, there is often a distortion in the shape of the lens or the cornea. Since both the cornea and the lens determine the sharpness of focus, these distortions will produce varieties of astigmatisms. They usually can also be corrected by an extra lens in front of the eyes.

The frequency of both types of handicaps increases sharply with age, although the number of elementary school-age children who need glasses is substantial. Since our ears were for-

tunately well designed to hold the frames of glasses, there is usually little difficulty in their use by even young children. But for reasons that are only occasionally understandable, many children with even severe losses in visual acuity go undetected for years. Their difficulties in reading, eye-hand coordination, and other tasks requiring good pattern discrimination are attributed to other causes, including mental retardation, brain damage, laziness, poor motivation, or whatever classification is currently popular. It is incredible how much clearer the world looks through proper eye glasses to someone who needs them.

A clouding of the lens called cataracts is another dysfunction associated with age, although a large number of children are born with it. Except in its milder form, no pattern perception is possible—only a sense of light and dark, since light can pass through the lens.

In most cases cataracts can be repaired by routine, simple, and brief surgery which restores clear vision. Up to the last generation, however, cataracts were usually untreated, and accounted for the overwhelming majority of instances of visual blindness. It is still a major cause of blindness throughout much of the underdeveloped world, although rapid strides are being made to eliminate it.

We will return to consider one aspect of cataract blindness later in this chapter. Children who are born with cataracts and then have them removed in later childhood or adulthood provide some fascinating information on the importance of experience in perceptual processes.

Muscle imbalance between the two eyes is another prevalent disturbance in the peripheral visual apparatus. It causes improper convergence of the eyes on an object being fixated, usually resulting in double images. The optical array from objects will not fall on corresponding areas of the two retinas. The visual system is normally arranged so that the orientation of the two eyes will bring the object being fixated on to the respective foveas. When this happens, any disparity in the optic arrays of the two eyes will produce depth rather than double images. This alignment is carried out by three sets of muscles which move each eye in three planes—up-down, right-left, and rotation. Normally, rather precise coordination of the two eyes is maintained to provide this alignment. Even slight misalignments will lead to eye dominance in which one eye is virtually suppressed at the expense of the other. This, of course, reduces the double image, but at the loss of all of the advantages of binocular vision—a wide field of view, stereoscopic depth perception, convergence as a cue to distance, and various binocular summations between the two eyes which are invaluable for good visual perception.

When detected early, muscle imbalance can usually be corrected by eye exercises, or simple surgery to restore the balance. If not attended to early in life, correction is far more difficult and often impossible.

In a very small percentage of people, brightness sensitivity and acuity loss, either over the entire retina or in specific areas, is due not to poor optical resolution, but to neurological dysfunction. In such cases, glasses are of little or no help since the image on the retina may already be as sharp as possible. Holes in the visual field—called glaucomas—are usually caused by a loss of function of the nerves serving that area. Sometimes this is evidence of a tumor in the visual projection area of the cortex where that part of the retina is represented. Sometimes the dysfunction occurs more peripherally, and may even be a loss of function in a group of receptors themselves, although the latter is a less likely circumstance. Occasionally there will be a reduction in peripheral vision due to a progressive failure of the rod receptors or the neural network into which they feed. This produces what is called "tunnel vision," in which the visual field narrows as if we were looking through progressively smaller tubes. If all rod function is lost, then the visual world has a lateral extent of only a few degrees instead of normally nearly 180°, and then only under very high levels of illumination.

Legal blindness is usually defined in terms of visual acuity, so that many legally blind persons do have substantial visual experience. Opaque cataracts will reduce acuity to an unmeasurable value, even though the perceiver may have no difficulty discriminating light from dark. In this sense, it appears as if although light is blocked from entering the eye, if it did so, perception could occur rela-

tively normally. This is true for most cataract patients following surgery except for those who were blinded by cataracts from birth.

Total blindness is a relative concept. Severance of the optic nerve is one extreme from which there is no recovery. For normal functioning, opaque cataracts cause total blindness too, even though some brightness discrimination is possible. Complete blindness may have many antecedents, a few of which are reversible. When it is not, then the perceiver must depend upon his other senses to perceive the environment. While detailed discussion of this goes beyond the scope of this chapter, brief mention can be made of two separate techniques that are useful in this regard.

The most natural procedure is to use our other senses in special ways to provide spatial information about the world. Thus, a blind person may use a cane initially to alert others that he is blind and needs help, then as an extension of his arm so that he can feel objects and the terrain at a greater distance from himself, and finally as a stimulus source for new auditory information. The latter is most important, although it is by no means the only new source of stimuli to which a blind person attends. Man's ability to locate objects in space by the echoes they send back is rudimentary compared to bats and porpoises, but can be used to locate large objects and discontinuities in the terrain after substantial practice. Thus, tapping a cane can be used to produce a sound which bounces off of objects and returns to the ear. Our temporal sensitivity in audition is precise enough so that the time that elapses between the tapping of the cane and the arrival of the echo can be analyzed by perceivers and used as an estimate of the distance of the object. This practice is somewhat easier to acquire after blindness, since both the motivation is high, and there are no other alternatives. But normally sighted persons can learn to do this equally as well as blind persons. There is no evidence that being blinded makes one supersensitive to nonvisual stimuli, only superattentive.

Related to this is the blind person's increased attentiveness to other nonvisual sources of information about his environment. Typically, a pedestrian will *look* to see which way traffic is coming, but this information is always available to us as differential loudnesses on the right and left, if we only attend to it. While it is obvious that other sensory information cannot entirely replace the lost visual details of spatial perception, substantial use may be made of it without any need to develop particular new perceptual skills.

A second technique involves retraining a different sensory system to replace some aspect of spatial vision. The most familiar is the tactile braille alphabet "read" by moving one's fingers over the raised dot patterns that form the symbols. This retraining is acquired in substantially similar ways to any complex detailed discrimination task, and usually requires several years of intensive practice and use before good proficiency is reached. Even so, reading rates are only a fraction of the comparable rates for sighted persons reading print. The important point is that the process appears to be rather comparable even if slower. The same kind of redundancy effects in braille reading are found; for example, faster scanning occurs for symbols spelling familiar words or predictable words. Further, scanning with two fingers is faster than one, even though not nearly twice as fast. Future work is needed to explore some of the other analogies, but there does not appear to be any fundamental difference between the two types of sensory inputs.

The braille-like process is being carried one step further with the Optacon process being developed at Stanford Research Institute. Here a series of 144 photosensitive elements, acting as a retina, scans a printed line of type. The pattern of light and dark areas, corresponding to the lines of the letters are translated first into electric codes, which in turn are used to vibrate 144 reed vibrators on which the blind reader places his finger. With substantial training one can learn to read letters represented tactually in this manner at rates over 50 words per minute.

An even more dramatic use of tactile sensations to mimic patterned visual stimulation is being developed by Bach-y-Rita at the Stanford Research Institute. A television camera is mounted on the perceiver's head. The resulting picture (somewhat similar to what a single eye in the middle of the forehead would see) is treated as if it were made up of a 20×20 matrix of points. Each of the 400 points that

are excited are treated as if the brightness picked up by the camera in that spatial position was above a given threshold. This output is connected to a spatial arrangement of 400 microvibrators placed in a 20×20 matrix over the skin. Thus, when a cell is illuminated by the television picture, the corresponding point on the skin is vibrated. With this procedure, Bach-y-Rita has produced a small-scale version of the retinal mosaic on the skin.

The critical question, of course, is whether a blind perceiver can learn to "perceive" the pattern generated by his new electronic eye. The answer so far is clearly yes. With sufficient practice subjects can learn to discriminate letters and numbers, and read with a proficiency approaching that for braille. More important than this, however, is the ability to move around in their environment, avoiding objects that jump into view as they swing their heads and reaching for objects they wish to touch or hold. The camera is equipped with a zoom lens so that one can attend to small details or wide vistas. Filters permit a wide dynamic range of adaptation. The exciting part about this work is that it offers a possibility of providing a spatial world perceivable at a distance for someone who cannot use his eyes.

This section has focused on several types of visual dysfunctions, ranging from acuity losses due to optical distortions, double images from muscle imbalances, loss of pattern information through cataracts on the lens, and loss of receptor or neural function in the retina or higher centers of the visual nervous system. We have also looked at some of the types of substituted sensory processes that are available when vision is greatly attenuated or lost altogether.

In some sense, these types of handicaps are quite easy to categorize and study, and most are easy to remedy, retrain, or substitute. The nature of the functional loss in perceptual behavior and skills is almost directly predictable from the mechanical dysfunction itself. If the eye will not focus an image, visual acuity is poor; if the peripheral retinal receptors are not operating, tunnel vision results; and so forth. However, there are many dysfunctions of perceptual behavior which cannot be traced to some mechanical distortion of specific failure of a component of the visual system. The breakdown in behavior is usually more complex and often related to losses in nonperceptual processing as well, especially language and other intellective dysfunction. We will consider a number of the perceptual aspects of these more complex losses, as we explain further the concepts of peceptual processing.

Perception of Objects in the Real World

One of the greatest controversies in psychology, extending back to antiquity in its general form and still pervading most theorizing today, concerns the degree to which prior familiarity or knowledge with the visual world is required in order to see the objects in that world. This argument is not yet resolved, either in perception or most of the other areas of psychology where it has left its mark. But it has helped pose the problems in ways which have led to new discoveries.

At one extreme are those who argue that the retinal projection of the stimulus at the eye contains sufficient information to permit the eye and the brain to construct a representation of a stimulus pattern with sufficient fidelity so that we can respond to it appropriately and see it as a perceptual experience consistent with other sensory and nonsensory information. This view has stressed a psychophysical correspondence between the objects in view and the resulting perceptions that arise from them. When different observers agree on their responses or their descriptions of perceptual experience, most of the information they used must have come from the retinal projection, since otherwise only by happenstance could all of their prior experiences be so identical.

The other extreme position has argued that the stimulus information is always ambiguous and that perception would thereby be ambiguous were it not resolved by our knowledge and expectations of what the world *really* looks like. This view has paid relatively little attention to how much information is contained in a stimulus itself (since according to this view it is never sufficient), but has rather focused on tasks on which the perceiver's expectations are uppermost in importance.

Neither of these extreme views are correct in themselves, although the former can handle a substantial amount of the explanations in perception. We shall consider it in some detail,

as it is particularly useful for those problems concerned with perceptual organization—how an organized perception is obtained from the visual features gleaned from the retinal projection.

The first approach has suggested that the retinal projection contains all of the information needed for appropriate construction of the perceptual world, but in what form is that information? How can we sort out those parts of the pattern in the projection that were reflected from one object or from one part of an object as distinct from another? Looking back at figure 2, we can see that while the projection contains reflections of gradients from different distances, they are all displayed on an effectively flat receptor surface of the retina. Hence, a three-dimensional world is first reduced to a two-dimensional one. Yet we perceive a visual world in depth, peopled not by gradients but by objects. It looks like a sorting-out problem of such massive proportions that we should never be able to see. However, like the aerodynamics engineer who pronounced that the bumble bee is designed in such a way so as to be incapable of flight, we should not be too hasty to claim that human beings cannot see. See they can, and it is the scientist's task to figure out how. While we cannot examine the entire range of answers here, a few of the most important aspects are illustrated.

Rules of Organization. One of the first tasks is to find some way of grouping together those visual features which arise from the same or related objects. Take one of the simplest cases—a single object seen in an otherwise empty visual field. How can we tell what is figure and what is ground? Are there any characteristics in the retinal projection or in the resulting visual features that would make this easy to do? There are several. The figure seems to stand in front of the background as if the background continues behind the figure but is occluded by it. This differentiation probably is made possible by the presence of the contours (a sharp discontinuity or gradient) surrounding the figure. Even more important probably are the differences in surface texture between the surrounded area of the figure from that of the background.

To demonstrate the power of texture gradients alone to help organize figures, figure 5 shows a number of examples taken from the work of James J. Gibson (1950, 1966). It has been Gibson's work on texture that has helped focus attention on the vast amount of information being conveyed by the content of the retinal projection itself.

These examples provide clear pictures of depth—surfaces and objects suspended in space—even in the absence of contours surrounding the objects and surfaces. Thus, part of a sorting-out processes appears to rest simply on the differences in the texture of the surfaces alone.

Adding a contour is also very important. In fact, it is nearly impossible to have an ambiguous perception regardless of how ambiguously it is drawn or represented. Figure 6 shows one kind of example. In A you can see a black vase on a white background, the vase being defined by its contours and the dramatic difference in color and texture between it and the background. But the same contour can also define a different organization—two white faces looking at each other as seen on a black background. However, you cannot see both of these "figures" at the same time, though it is possible to alternate the two perceptions. In B, the figure ground relationship is redrawn to reverse the ambiguity or ability to alternate between the two alternative views. Now the vase is in front of the background, and to see faces is much more difficult. In C, the vase is now background, through which more background is seen and the two faces are a more unambiguous figure.

We can restate this as a more general problem. A contour or a texture gradient defines a change, and thus can produce a shape or figure on either side. It is ambiguous therefore by definition. And yet perception is rarely ambiguous. What rules specify which perception will occur (in the previous example, the vase or the face)? Can we use these rules to specify what we will see in advance of actually seeing it?

One attempt to do this has been a major contribution of the school of Gestalt Psychology. They proposed a series organization principles to specify what would be seen. Figure 7 illustrates the most important of these principles with the aid of a number of relatively

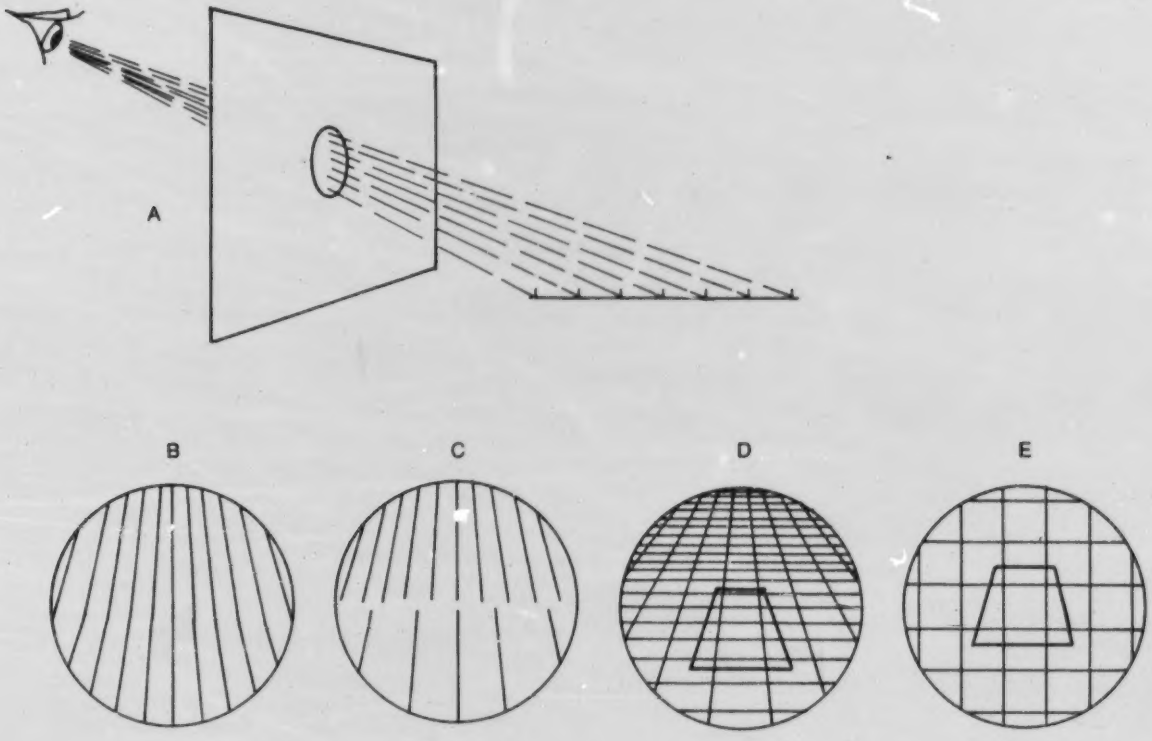


Figure 5.—Some examples of texture gradients. In A, the optic array from a textured surface is illustrated. From a uniform texture, as in a tiled floor, those parts farthest from the eye subtend a smaller visual angle than those parts close to the eye. This will be true regardless of the nature of the texture or the degree of slant. In B the texture is from a surface stretching away that then rises at an angle. C shows a discontinuity, where there is a step down to a lower level. D and E show how the same trapezoidal retinal shape can arise from two different read shapes, conveyed quite differently by the texture. In D, it is a square floor stretching away, while in E it is a trapezoid on a surface equidistant from the perceiver. (Taken from Gibson, 1950.)

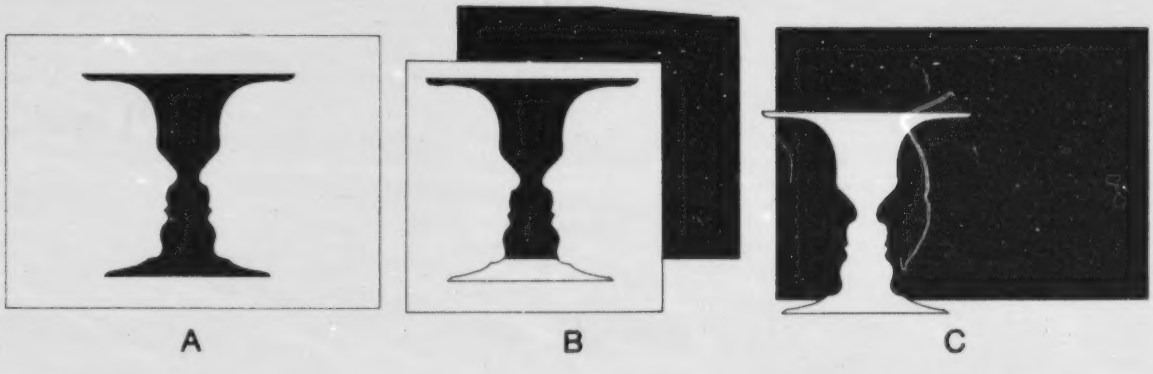


Figure 6.—The Rubin vase. In A the vase is shown as an ambiguous figure. In B and C the ambiguity is reduced to accentuate the organization of a vase, or as two figures respectively. (Taken from Hochberg, 1964.)

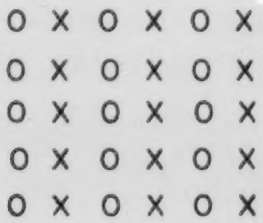
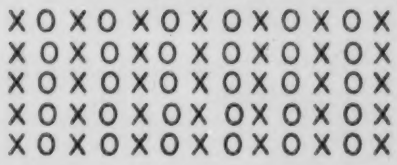
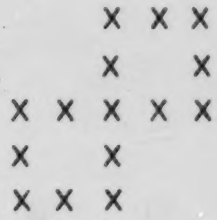


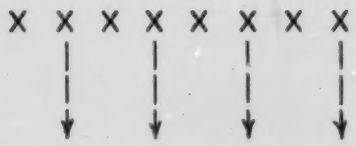
Illustration of similarity



Proximity versus similarity



The grouping of elements as good figures



The principle of common fate

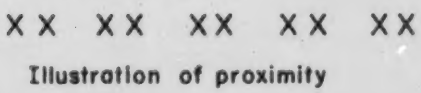
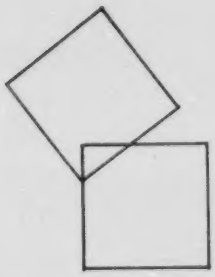


Illustration of proximity



The influence of good configuration

Examples of closure

Proximity versus closure

An illustration of good continuation

Closure can lead to two groups of elements

Figure 7.—Illustration of several of the Gestalt laws of organization.

simple line drawings. These drawings are themselves ambiguous in that they are susceptible to several organizations, but they are rarely seen as ambiguous. While each of these principles has an intutitive logic to it, the Gestalt psychologists were not especially successful in translating them into quantifiable statements which could be used to predict, ahead of time, the organization of perception.

Hochberg (see 1964, 1971) has taken several of these laws, and reduced them to a single one which he has called a *minimum principle*—the organization that is perceived is the one which keeps changes, discontinuities, and differences to a minimum. Hence, of two possible organizations we should see the simpler one. Just taken as this, Hochberg's principle is no more than a restatement of the earlier qualitative ones. What he has done, however, is to specify some physical measures for simplicity, so that a pattern can be measured along some of its physical dimensions and a prediction made which can then be tested against what perceivers say they actually see.

Hochberg and Brooks (1960) explored this with drawings of two-dimensional figures, which could also be seen as three-dimensional objects. Figure 8 shows several of these taken

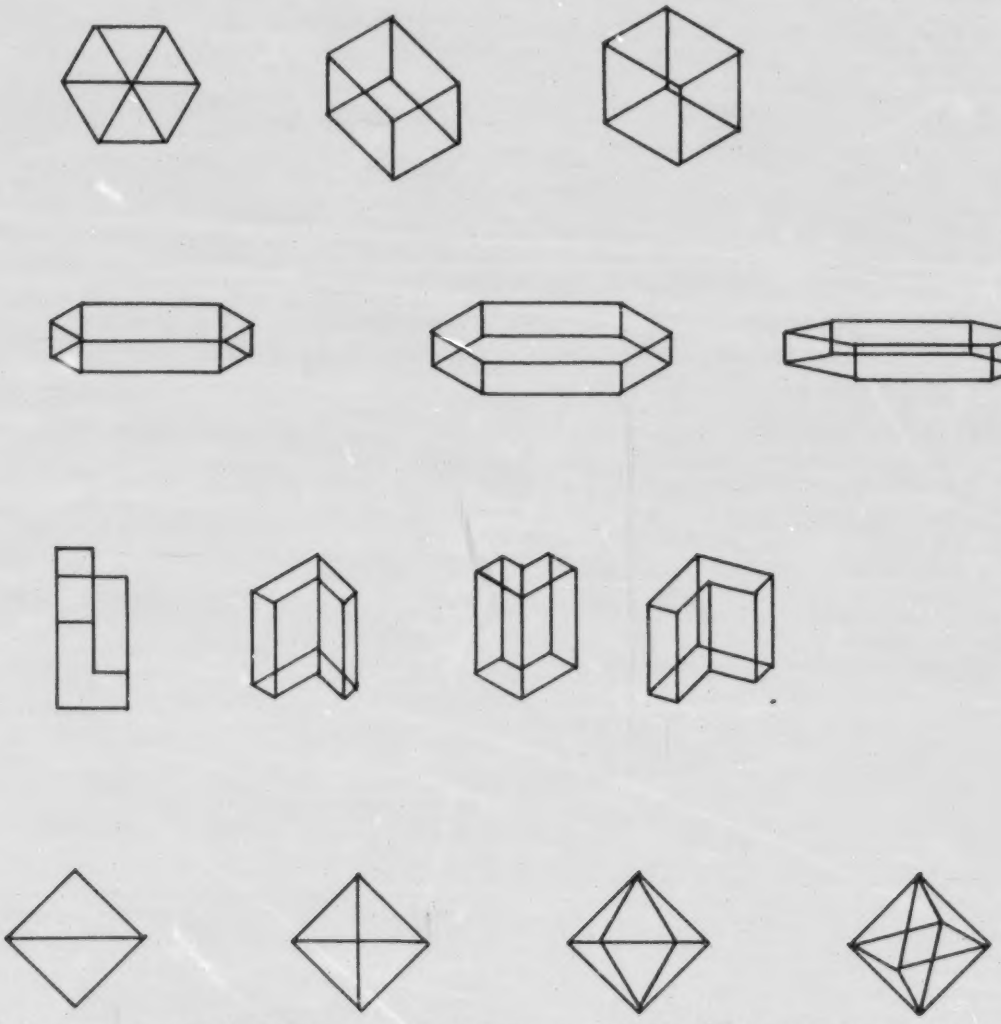


Figure 8.—Series of perspective drawings used by Hochberg. In each series the drawings differ in their simplicity as measured by the number of continuous lines (c), the number of angles (a), and the average of different angles (d). (From Hochberg, 1964.) See formula on page 56.

from one experiment. It is possible to see each member of the series as two or three dimensional. They examined several physical dimensions which they could relate to how perceivers actually saw them. For these they found a simple formula which worked quite well, following the principle that a member of a series will be seen as two dimensional when the two-dimensional representation is the simpler one, and three dimensional otherwise (with these stimuli, the only other alternative). For each member of each series they counted the number of continuous lines (c), the number of angles (a), and the average number of different angles (d). They then defined simplicity as $S = 2c+a+d$. This particular formula was the result of much testing and validation. Hochberg and Brooks then gave each figure to a new group of subjects and asked them whether they say it as two or three dimensional. They found, for a number of different series of drawings, that as the two-dimensional simlicity measure decreased, the perceivers were more and more likely to say they saw the drawing as three dimensional. While there are undoubtedly other physical dimensions that enter into simplicity, Hochberg's success in prediction has provided convincing evidence for the hypothesis that simplicity of organization is a determinant of what will be seen. It continues to possess the intuitive logic of the older qualitative laws of organization, while at the same time being open to measurement.

The argument can be carried further, since up to now we have only considered outline drawings of simple figures. As already mentioned, a three-dimensional object would project only a two-dimensional image on the retina, yet most scenes we perceive are in depth with three dimensions. Hochberg has tried to show that his minimum principle also will explain how the information in the optic array is used to determine the three-dimensional depth perception.

Space Perception. Following the arguments presented earlier, we should expect that the retinal projection contains sufficient information in its patterning to determine the perceptual organization, including the spatial arrangements among objects. Since it is projected on an essentially flat retina, depth as such cannot be spatially represented. In fact, the projection must present an ambiguous image on the retina, one which could theoretically be perceived either as a two-dimensional or three-dimensional scene. There are sufficient sources of information, however, to create a perceptual organization that is in depth. In fact, according to the minimum principle, depth is seen because these cues make a three-dimensional organization simpler than a two-dimensional one.

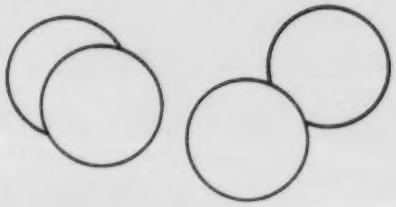
Figure 9 illustrates some of the basic monocular cues for depth—information contained in the retinal projection available to either eye alone. These are the cues one would use if one eye was closed. The most effective cues appear to be texture gradients, interposition, size perspective, linear perspective, and shading and aerial perspective.

To show how the minimum principle might be applied here (though qualitatively since the physical variables are more complex), consider figure 10, taken from Hochberg (1964). This illustrates four monocular depth cues, each of which could have arisen from a two- or three-dimensional spatial arrangement. In each case, the three-dimensional version seems simpler and more regular. This is especially true when all four appear on the same scene—clearly the simplest organization is that of a scene stretching away from the perceiver rather than a two-dimensional surface in front of the eye. It is the former that is perceived without ambiguity.

These depth cues are monocular—needing only one eye to be effective. Usually however, both eyes are open and this provides a binocular cue of very great power, especially for objects not too distant from the perceiver. Because the eyes are separated in space—about 65 millimeters for the average adult—the retinal projection reaching each eye is slightly different. This binocular disparity of retinal images producing stereoscopic vision can be simulated by taking a photograph of the scene from the position of each eye, and then viewing the pictures with each eye separately. It is clear that this is a powerful source of information about space and probably contributes greatly to perceptual organization of depth. But it is not a necessary cue, since depth can be experienced with only one eye.

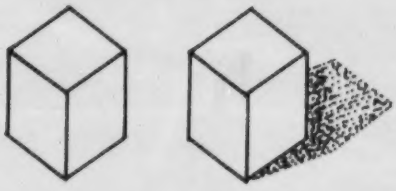
The story does not end here. All of the ex-

Size as a cue of depth

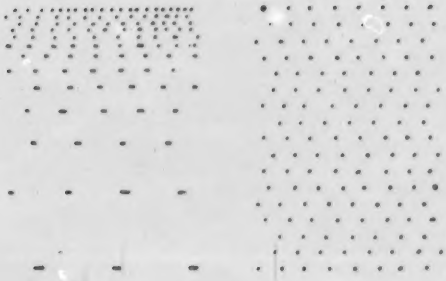


Partial overlap as a cue of depth

Attached shadow as a cue of depth



Cast shadows as a cue of depth



Texture gradients as a cue of depth

Filled space as a cue of depth

Figure 9.—Several examples of monocular depth cues.

amples have been of retinal projection emanating from stimuli and objects presented to the stationary eye, and this rarely occurs in nature. Our eyes, our heads and our bodies are in motion with respect to the world around us, and the objects and the world move in relation to us. Each of these movements present a different retinal projection to the eye. The succession of projections of the same scene can be perceived as the same scene undergoing some transformation, such as moving away or to the side, or as an entirely different scene in each view. The minimum principle clearly suggests that perceiving the same scene under-

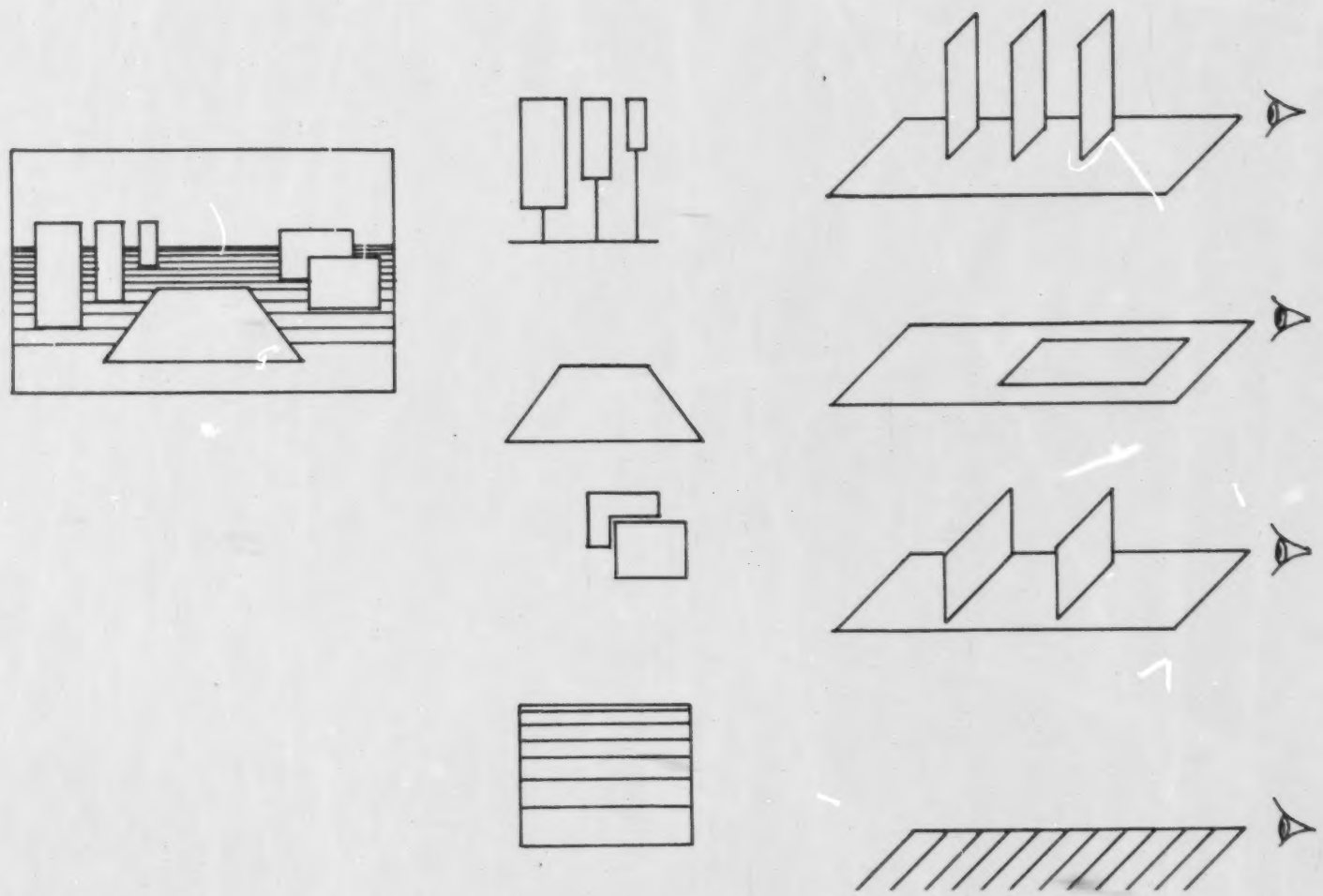


Figure 10.—The minimum principle of organization as applied to perception of depth. In A is a drawing of a surface, which can either be seen as stretching away from the eye (in depth) or as a flat two-dimensional surface. Four monocular depth cues are illustrated. In A1, the three posts could have been due to B1′ or B1″. Which seems simpler? In A2, the shape could be a trapezoid (B2′) or a square (B2″). Which seems simpler? In A3, one rectangle could be missing a corner (B3′) or be behind the nearer one (B3″). Which seems simpler? In A4, the textured surface could be progressively finer near the top of the picture (B4′) or could be stretching away (B4″). Which seems simpler? In each case, organizing the scene in depth permits the objects to be simpler—the posts are all the same size, the shape on the floor is regular, the two rectangles are the same, and the textured floor is uniform. For these reasons, according to the minimum principle, we perceive this flat scene in three dimensions. (From Hochberg, 1964.)

going some transformation, such as would be caused by our moving away or to the side, is a far simpler perception, especially if we have other cues that we are moving ourselves.

This becomes even more complicated, yet clearer, when we consider that usually not only are our eyes, head and bodies in motion, but that some of the objects in the environment move in relation to others. How can we tell when changes in the retinal projection are due to us moving or objects moving, or both moving? Again, it has been Gibson who pointed out that when objects move in the environment, there is a relative change in the patterns in the retinal projection from moment to moment. But when we move our eyes over a stationary environment, there is no relative change at all—all parts of the projection move together, with one side becoming occluded as it drops from view. Thus, a transformation within the projection is a cue to object motion, while a shifting of the entire projection, or a stretching of it, suggests the perceiver is moving with respect to the entire visual world in front of him.

Thus, while the projection focused on the retina at each instant in time may be ambiguous with respect to a resultant perceptual organization, the changes over time help reduce the ambiguity, not increase it.

The minimum principle makes it clear that little ambiguity should result in our perceptions. In fact, there would seem to be no way of fooling a perceiver about what he is seeing in the natural world around him. Perceptual organizations almost always will be veridical to nature. Only under certain contrived circumstances will illusions of nonveridical perceptions occur. Further, it is likely that something like the minimum principle operates as a function of the organization of the nervous system, rather than through learning. Perceptual organizations of figures on grounds which are located in space are constructed, but sufficient information to guide those constructions is contained in the retinal projection of the light reflected from the structure. No appeal need be made to our knowledge about what it is we are looking at.

This is not to imply that the perceiver's expectations cannot enter into the perceptual organization of what he constructs. A simple

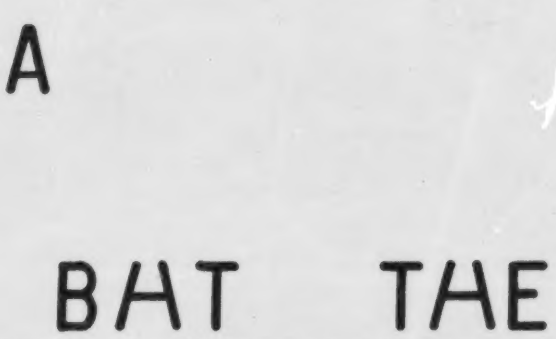


Figure 11.—An example of our expectation affecting our perceptual organization. (Taken from Neisser, 1967.)

example is shown in figure 11. The middle letter has the same physical properties and so should have the same visual features transmitted to the brain. However, we organize one as an A and the other as an H because of what we expect to be found in each place. Except for the fact that this is a demonstration and readers are on guard, nearly all viewers would perceive the top as closed or open depending upon which word they had seen it in.

The Perceptual Constancies. One of the most impressive, though often overlooked, phenomena of visual perception concerns the perceptual constancies. These are cases in which the perceptual organization remains relatively constant even though some or even most of the pattern within the retinal projection undergoes great changes. Shape constancy refers, for example, to the observation that doors and windows almost always appear rectangular regardless of the visual angle of regard, even though the pattern projected on the retina should be trapezoidal at all angles of regard except for that of straight ahead. Size constancy refers to the observation that heights of men do not appear to shrink as they walk away from us, even though the size of the man in the retinal projection continues to shrink. Lightness constancy refers to the observation that coal continues to look black even though the amount of light reflected from it changes, which should change its color and brightness. There are a number of other constancies, and they all share this same type of apparent discrepancy between the varying physical dimensions in the retinal projection and a constant perceptual experience.

Many explanations have been offered for these phenomena. A widely held one is that the perceiver "knows" what the object should look like, and from this knowledge and familiarity he can adjust his perception or construction accordingly. Thus, windows are always rectangular and never trapezoidal. Consequently, a trapezoidal window is invariably organized as a rectangular one. This type of appeal to prior knowledge has failed on a number of grounds, most noticeably that these perceptual constancies occur just as easily for totally unfamiliar objects for which we do not know their true shape, color, or size.

Another explanation has appealed to a kind of unconscious computation that the perceiver makes while looking at the scene. Thus, the door is rectangular because we can compute its slant with respect to the angle of regard. Since slant and shape are related geometrically, simple trigonometry would allow us to solve an equation to tell us "the true shape" given the shape on the retina, plus the slant of the surface (that information being provided by depth cues). Likewise, the size of the object can be perceived as constant if that perception is determined by the retinal size and the distance from the perceiver (also provided by depth cues). Each of the constancies could be explained by this kind of unconscious computation.

But this second explanation is unsatisfactory for several reasons, though it cannot be entirely rejected. The computations themselves would have to be carried out totally without awarenes and they do not seem to depend upon any training in geometry or any knowledge of the relationships between size and distance, shape and slant, or any other combinations. Further, there are some instances in which what is perceived is not predicted by the geometry of viewing situation (though no other satisfactory explanation has been offered for these failures, either).

Again, Gibson has offered a more interesting and much more reasonable explanation than either one based upon past experiences or unconscious computation. He argued that we have even stated the problem improperly. It should not be how to account for constant perception in the face of changing stimulation, but rather we should be looking for those

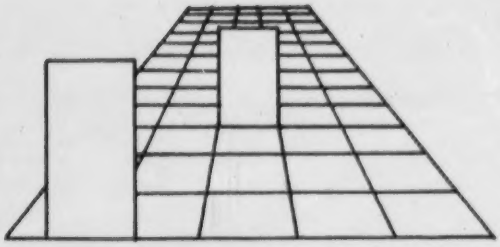


Figure 12.—Size constancy as a function of a constant texture gradient ratio. (Taken from Hochberg, 1964.)

aspects of the retinal projection which the observer uses in his construction that are *constant* with constant perception. Gibson has proposed several such aspects of the retinal projection, the most important being based upon texture density and changes in texture. We have already discussed texture gradients as cues used to construct perceptions of objects located in space. Look at figure 12. We perceive both a clear sense of depth and that each of the objects are about the same size, in spite of the fact that the retinal projection of the back one is one half of the size of the one "in front" of it. But if instead of concentrating on the size of the retinal projection of each object, one uses the ratio of the density of the surface texture near each object to the size of the object, these ratios are the same. Therefore, the two objects must be the same size. Another way to look at this is to consider how much of the texture is occluded by each of the two figures. While the far one is smaller, the texture is also finer, and the number of squares covered over is the same. This cue—the ratio of the size of the object to the size of the texture (or other nearby objects) *automatically* takes distance into account and yields a basis for the perception of size constancy. Hence, while the retinal projection contains objects of varying sizes, they are all perceived as similar in size if their true sizes are the same. Organization for Gibson is based on these ratios among components in the retinal projection.

Gibson's argument can be used to explain all of the perceptual constancies. It is the most reasonable explanation since it stresses cues from the entire visual field, not just from a single object. We yet do not have very much direct evidence of how these ratios of different

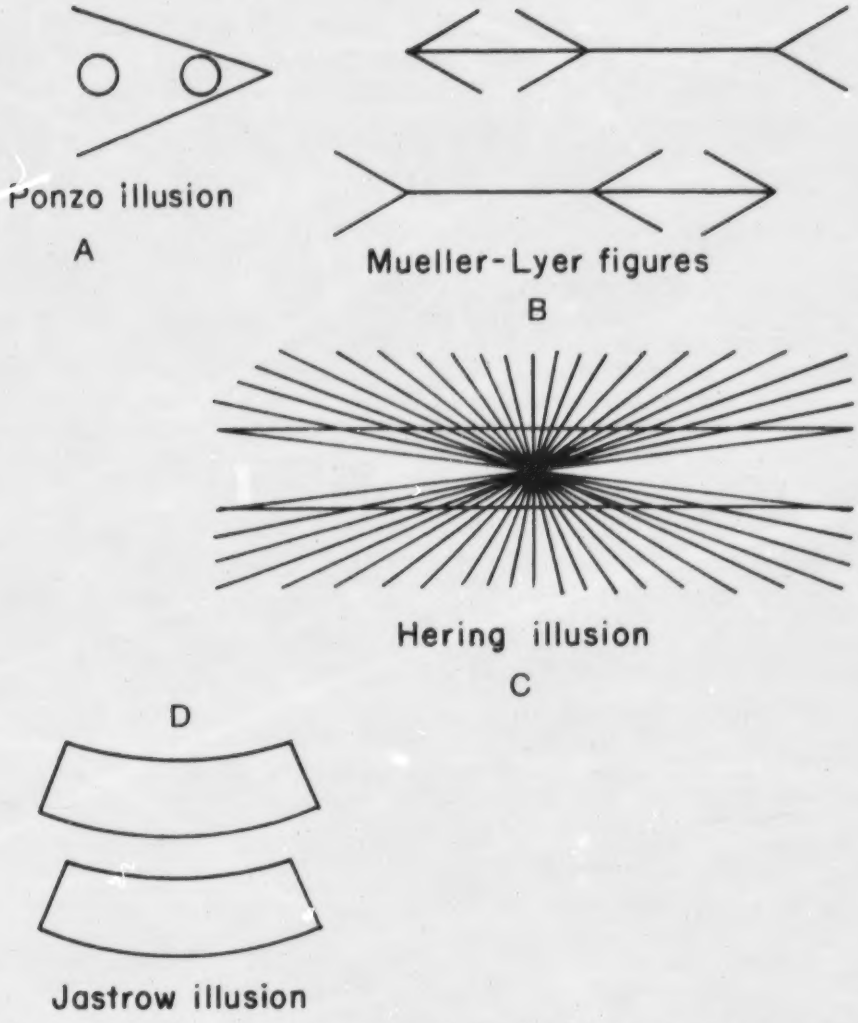


Figure 13.—Several simple outline illusory drawings. In A, the two circles are equal in diameter. In B, lines 1, 2, 3, and 4 are all the same length. In C, the two long lines are parallel. In D, the two sections are equal in size.

aspects of the stimulus enter into perception, but it seems clear that taking them into account can greatly simplify our understanding of perceptual constancies, especially since it is merely a continuation of the expanation for perceptual organization of any kind.

Visual Illusions. We commented before that a perceiver should never be fooled into making the wrong construction of a retinal projection. This ignores the ingenuity of psychologists to construct stimuli which will lead to illusory perception, even though such stimuli rarely exist in nature. These diabolical illusions are important to examine because we should be able to find some cues or properties of the retinal projection of the illusory stimulus which lead us to construct a perception which does not correspond to the stimulus.

Consider the examples in figure 13. In each, physically equal stimuli and therefore equal retinal projection are perceived as unequal. What causes this "error" in perceptual organization? A number of theories have been proposed, none of which are entirely adequate. One of the more promising, the perspective theory, suggests that there are some aspects

of each pattern which induce a sense of depth into the objectively flat drawing. If one part is seen at a different distance from another part, then this will lead us to perceive a difference in size, too, in order to compensate for the equal retinal projections. For example, in the Ponzo (railway track) illusion, the two converging lines suggest a linear perspective, with the converging point farther away than the open end. If that is the case, then the physically identical circle near the point should appear to be larger. A similar explanation can be offered for the Mueller-Lyer illusion. The inward pointing arrows between line 1 suggest a linear perspective such that line 1 is nearer to the observer than line 2, and hence shorter.

Developmental Aspects of Organized Perception. This section has focused primarily on the perception of adults. It has been safer to do so, since our knowledge is much weaker concerning how organizational characteristics develop with age or experience. Still, we are learning a large amount about perceptual development and some of this includes suggestions about how various kinds of perceptual handicaps might develop.

One of the most fascinating studies was reported by Senden (1932) in which he collected observations from a large number of patients who were blind from birth (usually with cataracts), and then given sight in late childhood or adulthood. These observations were often incomplete, and usually strongly biased by who the observer was, but they still provide important data. Since such patients typically had well developed language and conceptual skills, and had very familiar contacts with the environment through their other senses, they represent good subjects in which to assess the role of prior experience in visual perception. What can a newly sighted person do upon the first occasion of seeing?

Most patients report their initial experiences when the bandages are removed as unpleasant and uncomfortable. There is too much new stimulation, and many of them kept their eyes closed for a substantial time afterwards. There is even some reason to believe that some of the patients with severe cataracts suffered some neutral degeneration, either in the receptors or in their other interconnections to the cortex, so that they could never recover fully normal vision. We already commented that this is to be expected. But many patients clearly did not have such damage, and could begin to use their eyes to see.

One distinction was noticed in some patients almost immediately. If two objects are placed side, by side, he could tell whether they are the same or different. (He can also do this more easily if he is allowed to touch them, but that is cheating in this context.) But if he was shown first one, and then the other, so that both are not on view at the same time, he cannot make this distinction, and it takes him months of practice with even simple stimuli before such successive discriminations occur reliably. Similarly, the learning of names or the colors of objects is a slow and tortuous process. What evidence is presented suggests that the rate of naming objects is about the same as being able to perform the successive discriminations with them.

The perceptual learning process—being able to recognize an object as the same one that you saw before—is very slow for these patients, as the previous successive discrimination results would suggest. This can be seen in another way. If you show an object and try to teach the patient its name (something he may already be familiar with through his other senses), many trials will be needed until he can reliably produce the correct name. If, finally at this point, the perceptual view of the object is altered—in color, orientation, size, or perspective—the learning process has to start all over again. That is, what was learned was highly specific to the particular pattern of visual features persented—not an abstract or generalized organization. To get the latter, even more experience is needed, with presentations in many different contexts and orientations.

These results have many interesting parallels and implications. For example, they mirror to some extent what is found with normally sighted children over the course of typical development—successive discriminations are harder and take longer to learn than simultaneous ones, and the former are much more dependent upon having names or concepts available. It is possible that a similar process

may underlie many of the perceptual handicaps that appear in brain-injured or retarded children and adults.

Theoretically, the difference between simultaneous and successive presentation concerns the role of perceptual memory—being able to remember what we have seen after it is no longer in view. It suggests that the newly sighted may be capable of extracting the basic visual features, or having a rudimentary organized perception without much experience, but that once the object is out of sight, they no longer retain any memory of its features or organization.

Some recent research by Hochberg (1968) further implicates the role of meaningfulness and perceptual memory for these types of discriminations. He showed normal adult perceivers pairs of long words, and asked them to respond as quickly as possible as to whether they were spelled the same or whether they were different words. When they were presented close together in space, and in the same typeface and size of print, subjects were apparently able to make their decisions based upon the visual shapes alone. Thus, it took them no longer to respond, regardless of the meaningfulness or the familiarity of the words, or even whether they were English words or not.

Presumably, all the subject had to do was to compare the corresponding visual features between each word, and note whether any discrepancies occurred. He did not need to process the features further, or to name or remember them.

But note what happens when the words are not side by side. Now the perceiver has to look at one or more letters of one word, and then somehow remember them while he shifts his gaze to the other word. Now he is comparing his memory of one with his perception of the other. It does not matter now whether the typeface or size is the same. He still has to go through a naming process. The only way to compare spellings is to name the letters or comprehend the entire word. In both cases, perceptual labels and meaning are involved. Hochberg finds now that familiarity and meaningfulness matter a great deal. The easier the subject can understand the word, the more quickly he can tell if the two words are the same or not. Presumably, now the visual features are just the starting point for a more complete organization and naming process, and it is that organization or name which is remembered and compared.

By implication it is this that the newly sighted cannot do. It takes months of practice to build up such organizations and to attach names and meanings to them. Thus, successive discriminations cannot be performed by them initially.

To what degree might not some of the perceptual difficulties shown by some children and adults be related to the same distinction—being able to see, but not remember what was seen? Maybe we would find that some kind of perceptual handicaps reflect great difficulty in building up perceptual organization, or independently, they may have organized perceptions of the world presently on view, but not be able to remember what it was after the view ends.

There are further extensions of this type of problem. For example, much interest is focused on the role of verbal and conceptual mediation on perceptual memory. Flavell (1966) in one series of experiments, showed children a number of pictures of familiar objects, and pointed to them in a particular order. The child was then asked to point to them in the same order, after the pictures had been rearranged. He found that 5-year-olds did not spontaneously produce any vocalizations, or other mediators, to assist them to remember the order, while nearly all of the 7-year-olds did. Some 6-year-olds did, but some did not, and the ones who did had better memories for the order. More important, when Flavell suggested to the 5-year-olds that they might mediate, they were unable to do so. For those 6-year-olds who did not spontaneously mediate, most could do so after such a suggestion was made, and their memories improved. In this sense, 5-year-olds had a mediation deficiency, being unable to use it. Some 6-year-olds had a production deficiency, being able to do so, but not producing a mediation at the appropriate time unless prompted.

It is not clear whether the ability to mediate or rehearse perceptual experience in order to facilitate its remembering is part of the deficits underlying some kinds of perceptual handicaps. Most diagnostic tools do not permit a distinction between initial perception and subsequent memory. Even when the testing is done

with original stimuli present it may be arranged in such a way that no simultaneous comparison can be made, and therefore, requires good perceptual memory.

When discussed in this way, many perceptual deficits could be explained as poor perceptual memory without any initial deficit in perceptual experience. For example, nearly all children show some letter reversals when they begin to learn to print. This is not considered evidence for any pathology at ages less than 7 years or so, unless it dramatically interferes with reading and writing. Except in its extreme form, it may reflect nothing more than incomplete memory representations. The child may have internal constraints on his construction of the letters that are correct, but he cannot distinguish one of the several transformations possible, especially mirror image reversals. He might have no trouble while tracing, but as soon as he has to look away from the model to what he is drawing, his less-than-perfect memory manifests itself. By age 7 or 8 this deficit disappears, just as mediation production deficiencies seem to spontaneously disappear in the Flavell perceptual memory studies. For a few children it does not go away, but remains to plague their reading and writing as well as many other perceptual tasks. This may all be the result of some inability to develop and maintain a perceptual memory of what had been clearly and adequately perceived.

This section on the development of perception is not intended to be very broad in its coverage. Haber and Hershenson (1973) have an extended discussion of the recent literature on infant humans. This work shows rather strongly that most aspects of the perception of depth and space and the constancies is fully organized either at birth or within a few months thereafter. In this sense it is not learned, nor is it a result of long and complex interactions with the environment.

What is missing, however, is much knowledge about the individual differences in these perceptions, and especially in the role of visual impairment or perceptual handicaps in the perception of an organized visual world. Can such children use ratios of different textures? How does even simple impairment such as poor visual acuity affect these processes? We know virtually nothing about the answers to these questions; even though they might shed some fundamental light on both the typical course of development as well as the nature of the handicap.

Attention

Our sensory systems are continually being bombarded with stimulation, most of it either irrelevant or repetitious. Can we selectively attend to those aspects of importance and reject the rest? Looking at the other side of the coin, can we attend to two different inputs at once, two different conversations at a cocktail party, or listen to a conversation while driving amid heavy traffic? The answer to both of these questions appears to be yes. We can selectively tune out inputs, and we can attend to two different inputs—but the way that we do these is complex.

The selection of concern here is under the control of higher centers—it is motivated in the sense that selection is in terms of importance of stimuli to the perceiver. This is quite different from the more automatic selection that has already occurred on the retina or during the transmission of neural impulses to the visual cortex. For example, there are no visual features to represent continuity or sameness, only change, gradients, contours, and the like. Thus, the edge of a figure is signaled but not its center. Since the center of the figure, if uniform, can be coded in the same way throughout its extent, it is not necessary to represent any of it neurally. The brain must in some way fill it in even in the absence of information. While the filling in is constructive and may take into account expectations about the stimulus pattern based on prior experience, the absence of stimulus information about the centers or about any relatively homogeneous area of stimulation is an automatic selective process.

But there are a number of nonautomatic selections that are quite important, perhaps even the most important aspect of visual perception. We mentioned above simultaneous attention to two different inputs—can we divide attention? As an example, in an unpublished experiment by Neisser, readers were given a page of text in which the lines of print alternated in colors—the odd lines black, and the

even lines red. The reader was told to read the black lines out loud as he normally would, and be prepared to answer questions about the content when he finished. But he also was to attend sufficiently to the red lines so that whenever he noticed certain predesignated target words in either type of line, he should signal with his hand. It was found that when the target words were embedded in the red lines, they were rarely if ever seen. The only exception occurred when the reader's name had been inserted into a red line. That was nearly always noticed.

It has been recently shown that when good and poor readers are tested on this task, the poor readers are disturbed more by it than the good ones are. They cannot prevent their attention from straying to the irrelevant rows. Even so, they see and remember less about the content of the irrelevant rows. Thus, good readers seem to both perform better when distracting material is present, but still can find relevant information in such material. Clearly, they are better at dividing their attention than are poor readers, without at the same time becoming focused on irrelevant material as the poor readers seem to do.

This experiment is a visual example of what is called the cocktail party phenomenon—trying to listen to two conversations at the same time. A large body of experimental work has been done on exactly this type of problem, asking a perceiver to listen and usually repeat a message coming into one ear—the primary message, while remaining attentive to some special target word or idea embedded in a similar message heard in the other ear—the secondary message. The results in general from this type of task have been similar to those in the visual experiments. The target items are usually unnoticed in the secondary message unless those items alone are in a different voice or otherwise differ physically in some very distinctive way from the rest of the message. One of the few exceptions is again the ease with which listeners can hear their own name even in the secondary message.

These examples both involve a division of attention between two similar types of stimuli utilizing very similar types of processing skills. We have little success in dividing our attention here. When the division is between very dissimilar stimuli or tasks, then very little interference or deficit occurs, and both tasks can be performed together nearly as well as either alone. For example, student pianists have little difficulty in sightreading a new piece of music while at the same time being asked to report continuously an auditory message—no more errors are made in either task together than when either is done by itself (Allport, 1971).

When the tasks are similar, it appears as if there cannot be a true division of attention. Rather, processing of the two stimuli must be treated in succession, one after the other. If they both are continuous and arrive at the same time as in auditory messages, either the listener has to switch back and forth, or the secondary message is virtually ignored. It is possible to store one message briefly while constructing the content of the other, and then switch attention to the stored one. Such storage of visual stimuli has been shown to be possible for up to about half a second. What is stored seems to be the visual features themselves, so that construction is still possible if attention is switched back to those features within half a second. In audition, a comparable auditory storage appears to last a little longer, perhaps as long as a second or two. Unfortunately, there is no work yet on individual differences in the storage of brief visual or auditory presentation.

Since divided attention seems possible only when the stimuli and tasks are quite different, it appears as if we can construct multiple perceptions from visual or auditory features as long as the constructions themselves are quite different and involve different sets of processes. Thus, we would not expect to be able to read two lines of print even when they are different colors at the same time, but we should be able to read one line of print while at the same time trying to remember a tune or carrying on a conversation (a bit more difficult to do, but not impossible) or, even easier, tying one's shoes. In the Neisser experiment, we are not even attempting to construct the perception of the secondary message since we are under pressure to attend heavily to the primary one. The only reason a few of the targets in the secondary message are noticed is probably because of a brief shift of attention which must have occurred to the other message. This shift is more

likely if the secondary message contains some easily noticed feature that reliably signals the presence of a target, such as a change in the sex of the speaker's voice or a sudden shift in loudness. Apparently the drawing power or distinctiveness of one's name is so great that it "pops out" even in print we are not reading directly.

As a different example of selectivity we can examine focused attention—can we attend to one aspect of a stimulus and ignore all other parts? The usual reason we want to ignore a part is because by attending to the irrelevant parts we are impeded in our perception or in our response to the important parts. One of the most dramatic demonstrations of this interference was shown by Stroop in a test he designed. If you ask someone to look at a page made up of patches of color and to name the colors as quickly as possible, he can go quite fast and be accurate. He can go even faster if you ask him to name color words printed on a page in black ink. But what if you print color names (e.g., red, blue, green, etc.) in different colored inks? Thus, "red" would be printed in green ink, "blue" in red ink, and so forth. Now, ask the perceiver to name the colors of the ink, ignoring the words that are printed in those colors. The reader will have to take about 25 percent longer to do this, precisely because he cannot ignore the meanings of the words, even though they are irrelevant to the task.

Fortunately, nature does not design situations as diabolical as this one, but we have frequently been presented with unnecessary or conflicting information in which part of it could safely be ignored in order to proceed with the task in hand. But this is hard to do.

While many explanations have been proposed to explain why the Stroop effect occurs, much of the answer seems to lie in our inability to block the response to the irrelevant parts—so that the meanings of the words denoting irrelevant colors interfere with the names of the colors to be named. This means that all of the stimuli—both colors and words—are perceived and processed, and the interference occurs after that.

In the more general case, focusing of attention does not seem to occur as a perceptual process. That is, it does not involve a failure to perceive the unwanted part of the stimulus. Nor is it a failure to construct it into a perception, especially if the wanted and unwanted parts are made up of the same visual features as in the Stroop test. If the features are different, as in the red and black lines of print, then we can easily focus on the black and ignore the red.

One of the most interesting aspects of focused attention has concerned motivated focusing, more commonly called perceptual defense. Personality theory, especially Freud's psychoanalytic theory, stressed that we should be able to block out of awareness those stimuli which would create intolerable anxiety. Unfortunately, it has been nearly impossible to test this in the laboratory, both because of the difficulty in carrying out an acceptable experiment involving a high level of anxiety, and because of the methodological problems inherent in this type of experiment.

We have considered several aspects of selective attention. We are not able to divide attention between two similar stimulations arriving at the same time, unless they involve different constructive processes. When they are similar, then we can only switch attention back and forth. We also have trouble focusing attention on one stimulus, ignoring other aspects, again except when the aspect to be ignored uses different visual features or involves different constructions.

These results on various kinds of selective attention tasks have been primarily shown with adult subjects, although the general pattern is also found with children, often in accentuated form. Some theorists have even characterized the development of perception as primarily a change in the control of attentional processes. Unfortunately, much more research is still needed to document this clearly, although much evidence points this way now. Of course, children are both easily distractible, and easily riveted to a task in the face of other distractions. These are both aspects of attentional mechanisms.

In considering many forms of perceptual deficits, especially those that seem to be associated with some form of brain injury, attentional mechanisms are undoubtedly implicated. Brain damaged children are often described as having poor attention spans—they can-

not pay attention for even short periods of time. They are seen as hyperattentive; they cannot screen out stimuli, but attend to them all. They cannot tell the important from the trivial. They have no filter. They cannot focus their attention in ways that most perceivers can do rather easily.

This distractibility can be seen at even simple perceptual tasks, such as copying a line drawing or finding a figure within a more complex or detailed one. It is as if, when following a line which intersects on an irrelevant line, which usually should be seen as the background or from another figure, the new line now becomes the focus of attention so that the figure in question is lost or distorted.

Such a distractibility could arise from a number of sources, one of which, again, might be poor perceptual memory. One cannot focus attention if he forgets part way through the task what it is he is focusing on. Finding a hidden figure would be notoriously difficult if every time you looked from the exemplar to the complex picture you forgot what the exemplar looked like. Thus, the failure might be due to poor memory, and not to some inability to maintain figure ground organizations. It is unlikely that all abnormal distraction is due to perceptual memory failures, but some of it could be of that form. Much more is obviously involved, of course, since such distraction occurs in nonperceptual tasks as well.

Attentional problems are often found in the opposite direction as well—what is called fixation on an aspect of the task well beyond what the appropriate task demands. Here, the focus of attention is too great, so that other stimulus components pass unnoticed. Whether this has a perceptual or attentional base is not known, but it seems more likely to be due to some type of motivational fixedness such as avoidance, rather than to any inability to notice or attend to a diversity of stimuli.

Reading

The ability to read is undoubtedly the most complex perceptual cognitive skill that is routinely performed by human beings. It can be taught to young children without too much difficulty, or even without a good agreement on the best teaching methods. It can even be taught to adults who have been illiterate all of their lives. It has only been recently that the dependence of reading upon perceptual processes has been explicitly recognized. The first step has been to measure the movements of the reader's eyes while he reads a page of print. Figure 14 shows schematically a typical pattern for an average reader. Note that the eyes move in discrete jumps and then remain fixated briefly before jumping to the next fixation. An average adult reader remains fixated for about one-fourth of a second, and then shifts his eye to the next fixation point in about 1/20th second. Given the distance that the page is normally held from the eyes, the limits of good visual acuity would permit the reader to clearly see the letters of only slightly more than one word, though he can probably notice gross details beyond that, such as extra large spaces denoting the end of a sentence and the ends of the lines of print.

This analysis of the fixation pattern indicates that typical readers do not look at every word, nor in fact do they need to see every word in order to read continuously. This should be expected since reading is a very good example of constructive perception. The reader needs to develop some sense about what the sentence or paragraph, or page is about. This implies that the fixations should be much closer together (almost on every word) near the beginning of a paragraph or when it is clear from the context that the content is about to change. As the reader develops a sense of what it is he is reading, he can use this to guide his constructions. It is as if we form a hypothesis about what we will find on the page and then check it every few words to verify it, revising the hypothesis as we go along. If the content is quite predictable based on the hypothesis, less verification is needed and eye movements can be farther apart, leading to an increase in reading speed. If the writer should suddenly change content without warning, then the reader may find that he cannot figure out the content, since his hypothesis is now inconsistent with the words that he missed. This view of reading is elaborated by Hochberg (1970) and by Kolers (1972), as just two examples.

How is this view of reading consistent with the impression that we perceive every word on every line? The simplest answer is that we

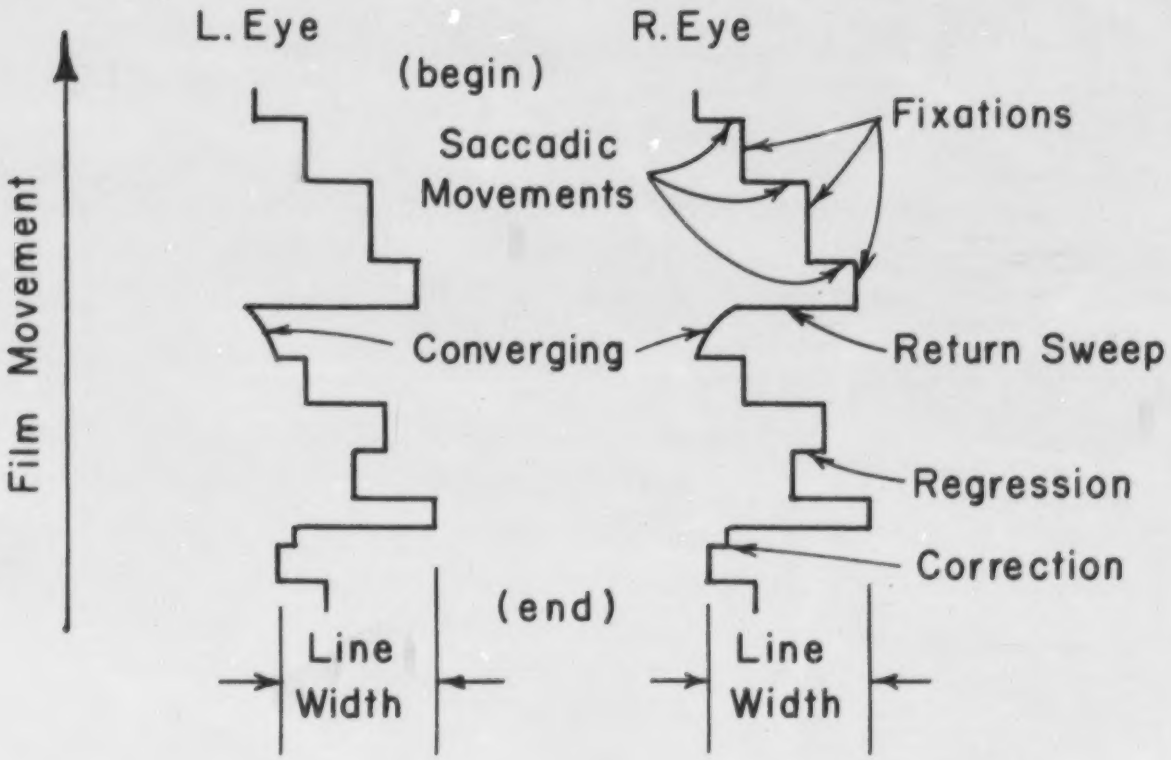


Figure 14.—Schematic representation of the record of eye movements obtained during reading. The length of the vertical lines gives the duration of fixations; that of the horizontal lines, the extent of lateral eye movements. Beginning at the top, the record shows four fixations and three saccadic movements in reading the first line of print. The eyes diverse slightly during the first return sweep and slowly converge to the correct position at the beginning of the second line. There is a regressive movement along this line. The return sweep on to the third line failed to bring the beginning of that line into clear view, and so a corrective movement occurs there. (Taken from Alpern, 1971.)

construct all of the words because we "know" that they are there, based upon an hypothesis, even though we do not actually fixate them. We probably can find some vague sense of word boundaries—the sizes of words, and perhaps even some visual features of the nonfixated words, particularly word shape. These features facilitate the construction of the nonfixated words. This is related to the difficulty we have in noticing typographical errors. Most of them go completely unrecognized because our strong expectations or hypotheses about what letters are present in familiar words will override the actual visual features of an erroneous letter. Hence, we construct the correct letter, even though the stimulus contained a different letter, and we construct and perceive words that we did not actually look at.

This view of reading places heavy stress on our abilities to construct sense out of partial information. We know from other experiments that if readers are given a text to read in which every other word has been removed, they still have no difficulty in reading it and having full comprehension. Hence, it should not be necessary to look at all the words. Further, we know from studies with readers of different speed that speed is gained by making fewer fixations farther apart, not by making briefer fixations or moving our eyes more rapidly. In fact, the duration of fixations, and speed of eye movements in reading seem to be relatively invariant over reading speed or difficulty of the material (see Kolers, 1972). Thus, learning how to read faster seems to be more a task of generating larger and better hypotheses and

trusting to them, even if we check them against the actual text only infrequently.

When discussing perceptual handicaps, reading is one of the most important topics, because nearly all such handicaps affect reading abilities as well. This is not surprising for several reasons. As implied earlier, reading is probably the moxt complex perceptual-cognitive skill we normally possess. It involves not only language processes, but rests upon incredibly rapid perceptual activity derived from sequentially presented brief exposures of complex information. Further, since it is so dependent upon constructive processes, anything which disrupts the translation of ongoing perception into perceptual memory—the heart of construction—will have disastrous consequences for reading skills. But reading may suffer for other reasons that go well beyond its perceptual components. It probably suffers when there is any malfunction, so that it is difficult to present any coherent explanation of dyslexia, let alone proposals for prevention, early diagnosis, and treatment.

It has been pointed out in auditory perception that sound inputs can be classified into two types—speech sounds and all others. Once the auditory system decides that an input is speech, all processing from that point on is qualitatively different, including even the part of the brain in which the processing is done. While the evidence is not yet this clear for vision, it is beginning to look as if all visual stimuli can be classified into two types—at least for literate perceivers—printed language, and everything else. When the input is classified as letters of words, then the nature of the processing from then on is qualitatively different in many respects. Even the brain centers involved may be different, since laterality effects (which side of the visual field is seen better) are often different for print as compared to all other stimuli.

While the distinctiveness of speech and print inputs from all other types may at first glance seem surprising, there are many reasons for it to have occurred. There are far more specific constructive processes used to perceive, organize and remember language symbols than any other type of input. Further, the two systems—speech and print—are closely allied. In fact, many theorists of reading argue that auditory representations of visual print stimuli are a necessary component of the reading acquisition process. Children do invariably vocalize as they read. Even for adults, there is substantial evidence that perceptual short-term memory for letters and words is auditory. Thus, when we make errors in reading or even in perceiving single letters, the errors represent auditory confusions with similar *sounding* words or letters, not similar *looking* ones. The letters in this case were correctly perceived, but incorrectly remembered—a perceptual memory for visual stimuli that is no longer visual but auditory (Sperling, 1963; Hochberg, 1968).

There is some very recent evidence and as yet not very well verified that dyslexia is much rarer among children who read languages with pictographic symbols (for example, Chinese or Japanese). There are fundamental differences between such a language system and English, for example. In the latter, a relatively small number of characters are used, each entirely arbitrary, and conveying no meaning in itself (that is, an M does not "look like" Mother). The English system has a set of rules which will permit anyone familiar with them to pronounce any word made up of these small numbers of symbols. Thus, by 9 years of age, schoolchildren who are taught the phonetic rules can pronounce almost any word in their language, even if they have never seen the word in print or heard it spoken before. The meanings of the words and the combinations of words are totally independent of their constituent parts—the letters—even though they can all be pronounced. One bizarre form of dyslexia is the ability to read without any comprehension at all. Most of us experience this occasionally when reading silently, but this can also occur in oral reading.

The Chinese graphic system places very different demands upon the reader. With it, there are many thousands of symbols, and knowledge of about 5,000 to 10,000 would constitute literacy. The meanings of each symbol are conveyed by the symbol itself, quite independent of any pronunciation. In fact, in China today, the two principal languages each use the same symbols. Thus, someone from Canton could read a Peking newspaper, and vice versa. But people from the two cities

could not converse at all, since the pronunciation of the symbols in the two languages are dramatically different. Hence, the meanings are the same, but their spoken representations are mutually unintelligible. Quite the reverse occurs in most European languages. English pronunciation rules will permit one to pronounce many of the words in most other European language but there would be no comprehension of what these words mean.

Thus, English and most other nonpictographic languages use few ysmbols and have a generative system to give rules on how to combine them for pronunciation. These rules tie the visual and auditory systems closely together. The few rules are mastered relatively easily by most children in a year or two, since they build upon spoken language which has preceded reading by 3 to 5 years of experience. Further, spoken vocabulary is very large by the time reading begins, so that once these rules are mastered many words are added to the visual recognition vocabulary quite rapidly.

Chinese, on the other hand, represents quite different tasks to the learner. Here the child has to master two independent tasks. He has to learn by rote memory the meanings of all of the symbols, and at the same time learn also by rote memory how to pronounce each of them. Even though he may already have been speaking the language for several years, that experience is not nearly as useful to him as comparable background is to a child learning English or French. Kolers (1970) has a more detailed discussion of these points.

At first glance it would seem that the Chinese child has a far more difficult time of it. Maybe so, although we have no data on relative rates of reading acquisition. But if dyslexia really is rarer in China and Japan, then the absence of the generative quality to the language, and the absence of an intimate link between the pronunciation and the graphic forms may protect them from one of the most serious perceptual disabilities known.

Summary

Visual perception is a constructed achievement, in which the patterned retinal projection of light reflected from objects and surfaces in the visual world is first represented as a set of visual features. From these features, an organized perception is constructed. This chapter has discussed a number of aspects of this process, both with respect to the structure of the visual system, how perception is organized and selected, and how some of the perceptual disabilities might arise.

Perception cannot simply be a copy of the retinal projection coming from a stimulus. Neither the structure of the eye, nor the nervous system are designed in this way. Light enters the eye as it is reflected from surfaces in the world around us. It varies in wavelength and intensity, and to the degree it varies in these, it is patterned. The retina, the photosensitive part of the eye, has the retinal projection focused on it by the cornea and lens. The rod photoreceptors are very sensitive to minimum amounts of intensity, while the cone receptors, packed closely together primarily in the fovea, are very sensitive to differences in the patterning of light.

The photoreceptors are organized into receptive fields, with each receptive field signaling a cortical neuron in the visual projection area of the brain. Each receptive field responds to only a narrow range of visual features—such as a line of a specified width, orientation, and color. Thus, much of the information about the patterning of stimuli is automatically encoded.

The sensitivity to minimum amounts of energy is determined by the adaptation state of the receptor, and the criterion used by the perceiver to evaluate whether what he observed could not have been due to random "noise" in the nervous system.

The acuity with which we can discriminate small differences in patterns is determined by the sharpness of focus of the optic array on the retina. Failure of good focusing can be corrected by wearing glasses. Acuity arises as a brightness discrimination between adjacent cone receptors, which are capable of responding to a difference of less than 1 percent in the amount of light falling on two adjacent cones.

To understand how organized perceptions can be constructed from the visual features received by the brain, it is necessary to recognize how much information about the stimulus is contained in those features. Especially important is the information in texture gradients,

since clear perception of three-dimensional objects located in a three-dimensional world can be achieved on the basis of texture cues alone. Further, laws of organization have been specified to explain which perceptual organizations will occur, even from seemingly ambiguous information from the stimulus. A more general statement, called the minimum principle, says that the perceptual organization achieved will be the one which uses the visual features to minimize discontinuities, and maintain simplicity. Several examples of the operation of this principle are illustrated, both for perception of objects and for the perception of objects in depth.

The perceptual constancies and some illusions are shown to be further examples of perceptual organization. The constancies, in which our perceptual experience remains constant even though the retinal projection is continually changing, are explained by noting how ratios of features within the projection are constant. Most of the visual illusions seem to occur because the organization seems to add a dimension of depth, which result in corresponding changes in size.

Several examples of selective attention are considered, especially how we can divide our attention between two stimuli presented simultaneously, and how we can focus our attention on one of them, ignoring the other. Division does not seem possible for similar stimuli, without a rapid switching or focusing of attention between them. Focusing is easy to do when the stimuli are different—then little interference is picked up from the unattended parts. When they are similar however, interference usually results.

Finally, reading was briefly considered as a perceptual skill, so that the role of eye movements and constructive processes could be examined. The similarity between speech perception and reading was noted, and some comments were added about how that similarity might make reading more susceptible to disruption from other cognitive handicaps.

In a number of places in the chapter, comments have been advanced about how normal function and dysfunction might be related and understood. Especially important is the distinction between perceptual organization, and perceptual memory.

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3. MEMORY

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In a very general sense an individual could be said to have memory for an event if his properties were in some way changed by the event. This definition of the field of human memory is far too broad. It includes all of the aspects of what might be called "physical memory" such as the persistence of a scar on the surface of the skin as a result of a previous injury. It also includes what might be called "biological memory" such as the changes in the heart and circulatory system in general that accompany several weeks of a regimen of exercise or "immunological memory" which includes the production of substances within the body that either increase or decrease one's sensitivity to allergens. Finally, the general definition encompasses all types of what may be called "psychological memory," which is a change in the nervous system as a result of sensory, motor, or conceptual experience. No single memory system underlies all these diverse types of memory, and it is unreasonable to attempt to consider them within the same theory.

Furthermore, the various types of psychological memory are not thought to reflect a single underlying memory system. It is probably necessary to distingush fatigue and adaptation effects as well as "sensory memory" (visual, auditory, tactile, etc., afterimages or persistence of vision, persistence of hearing, persistence of touch, etc.) from what might be called "conceptual memory." Conceptual memory refers to a presumably central memory process that includes in an integrated system both short-term and long-term memory for relatively well perceived events. Memory for pictures, stories, paired associates, serial lists, and so forth are all examples of conceptual memory. Virtually all of the psychology of human learning and memory is concerned with conceptual memory, with a few exceptions, such as the series of studies initiated by Sperling (1960) and others on visual sensory memory and studies by Broadbent (1958) and others on auditory sensory memory.

The present chapter is organized into four sections: experimental methods, coding, dynamics, and retrieval.

The experimental methods section briefly describes some of the major experimental designs and procedures used by psychologists in the study of memory in human subjects. This section will discuss some of the theoretical advantages to using some of the newer three-phase, probe, and continuous designs as opposed to the older, more confounded designs such as free recall, memory span, serial anticipation learning, and paired associate learning. Also, the greater theoretical simplicity of tests of recognition memory, as compared to recall tests, will be discussed. Finally, the special problems encountered in studying memory in children, especially those with verbal handicaps, will be discussed. Experimental methods which yield data for normal adult subjects that are easier to interpret theoretically may in some cases require the use of instructions that are too difficult for a particular group of handicapped children to understand. In such cases, this may require the use of other designs which do not require such difficult instructions. Alternatively, it may be possible to use the superior design, if sufficient time and ingenuity can be devoted to the instructions to subjects. In addition to the choice of a basic paradigm for studying memory in handicapped children, a variety of other methodological issues will be briefly discussed: session length, rate of presentation, modality of presentation, types of materials, instructions regarding learning strategy, etc.

The last three sections of this chapter present the theoretical principles of memory and discuss possible applications to children with different types of handicaps. In each section, both the obligatory structural (*capacity*) aspects of memory and the optional *strategy* aspects of memory will be discussed.

The coding section is concerned with the logical, qualitative aspects of the representation of memory traces in the nervous system. The retrieval section is concerned with the logical, qualitative aspects of the usage of the

information stored in this memory. The section on dynamics is concerned with the temporal, quantitative aspects of acquisition, storage, and retrieval in the memory system.

The reader should note that this organization differs in some important respects from an organization around the three temporally-distinct phases of memory: acquisition (learning), storage (retention), and retrieval (recall, recognition, etc.). Coding is concerned with the logical structure of memory as it is established during acquisition, as it persists through the retention interval, and as it is used in different retrieval tasks. Similarly, the dynamics of memory is concerned with the temporal quantitative aspects of memory during all three phases: acquisition, storage, and retrieval. Finally, the retrieval section is concerned with only the logical, qualitative aspects of retrieval in different situations (the rules and strategies of retrieval). The quantitative temporal aspects of retrieval are discussed as a subsection of the dynamics section. I believe that this subdivision of the field of memory into three content areas is superior to others in the degree to which the phenomena discussed in each area are independent of the phenomena discussed in the other areas. However, there are still a number of points of interaction between the principles and phenomena discussed in the different sections, and some of these will be pointed out.

In each of the three theoretical sections of this paper, certain principles of memory will be discussed along with some of the supporting evidence. I have decided to present a relatively definite, precise theory of memory in this chapter. It must be emphasized that this is my personal theory of memory. The field is hardly a finished area of scientific inquiry. Other memory psychologists would disagree with many of the principles, and the reader should keep this in mind.

However, a clear understanding of learning and memory can come only from a precise, integrated, and general theory of memory, however wrong some components of that theory may later prove to be. Since such a theory must delineate the separate component processes involved in memory, it directly indicates the variety of different aspects of the memory process that may be selectively impaired in children with different types of handicaps. Thus, it seems to me to be particularly appropriate to the present chapter to present the important phenomena of memory within such a theoretical framework.

In each of the three theoretical sections of this chapter, a number of possible applications to children with different types of handicaps will be discussed. The types of handicaps discussed include mental retardation, hearing deficits, speech deficits, visual deficits, learning disabilities, and emotional disturbances. Within the theory of memory presented in this chapter, it would seem inconceivable that all of these different types of handicaps would have the same general pattern of memory deficits. The present chapter will discuss certain specific patterns of memory deficits that might be expected for different types of handicaps. In addition, some suggestions will be advanced for the training of children with different types of handicaps.

Even within one of the above categories of handicaps, it is likely that there are a variety of different subcategories of individuals with this handicap that have rather different patterns of memory deficits. The category of "learning disabilities" is probably quite diverse with respect to the reasons for the learning disability (e.g., Sabatino, 1968). Hopefully, the separate components of memory described in the present chapter will provide an index to different possible patterns of deficits in different handicapped children. In addition, perhaps some of the newer experimental methods used in the study of memory in normal subjects can be used to advantage to diagnose the nature of a memory deficit in different handicapped individuals. Finally, one can hope that more detailed and adequate diagnosis of memory deficits, in conjunction with a more adequate theory of memory, will indicate better means of training and educating such individuals.

Experimental Methods

Whether in a memory experiment, school learning, or everyday learning, there are three distinguishable operational phases of human memory: learning, retention, and usage. The learning phase refers to the period of active study or exposure to the material and

the thinking that may accompany or follow such exposure. As a result of this exposure and the subsequent processing, some change is made in the nervous system. This change is called the memory trace. Following the learning phase, the memory trace must be retained over a period of time (retention phase) until there is some occasion to reactivate and use it (usage or test phase).

In memory experiments it is desirable to be able to alter independently the time and other conditions for learning, retention, and usage of information. However, when many items are presented to be learned, the learning phase for each item overlaps with a portion of the retention phase for previously studied items. When many items are tested, the usage phase for each item overlaps with a portion of the retention phase for all subsequently tested items. It is desirable to distinguish the learning, retention, and usages *phases* of a memory experiment for each item from the learning, retention, and usage *periods* of the experiment with respect to the entire *group* of items. When it is necessary to distinguish these concepts, the terms learning, retention, and usage *phases* will be used to refer to individual items and the terms learning, retention, usage *periods* will be used to refer to the entire group of items. Thus, when many items are presented to be learned, the presentation time for the entire list of items will be referred to as the learning period for the group of items, though this includes both learning and retention phases for individual items. Similarily, when many items are tested, the entire period of testing will be referred to as the usage (test) period, though this includes both retention and usage phases for individual items.

It is of some importance to distinguish the operational phases of a memory experiment from the theoretical phases of the memory process in a human being. To aid in maintaining this distinction, it is helpful to use the terms "acquisition," "storage," and "retrieval" to refer to the theoretical phases, with the terms "learning," "retention," and "usage" referring to the independently manipulable phases of a memory experiment or real-life memory situation.

The principal reason for making this distinction at the present time is the possibility of a fourth theoretical phase, consolidation, which may intervene between the acquisition and storage phases of the memory process. Although there is some evidence for some type of consolidation process occurring in the formation of human long-term memories, the exact nature of this process is not at all understood. It may be that consolidation can be considered a part of the acquisition phase. Alternatively, it may be possible to consider it as part of the storage phase. However, it is also possible that consolidation needs to be considered as a separate phase of the memory process. Hasty identification of the operational phases of a memory experiment with the "corresponding" theoretical phases could lead to an ignoring of this final alternative for the formulation of the consolidation process.

Study-Test (Three-Phases) Designs

From the standpoint of achieving independent control of each of the three operational phases of a memory experiment, the ideal design is one in which the conditions for the learning, retention, and usage (test) phases can be manipulated at least somewhat independently of each other. Such a design will be called a three-phase design, though the more common name is probably the study-test design.

Single-Element Memory. The design that in many ways comes closest to the ideal three-phase design is that originally developed by Brown (1958) and Peterson and Peterson (1959). In the Peterson and Peterson design, a "single" item (consonant trigram) is presented, followed by a three-digit number which signals the *S* to begin counting backwards by three's from that three-digit number until a signal to stop is given, at which time the *S* is to attempt to recall the single item.

Obviously, this same basic design can be used to study recognition memory where the single item is presented again at the time of test and the *S* is required to say "yes" or "no" concerning whether the test item is the same as the previously presented item. The recognition test could also be multiple choice, involving presentation of two or more test items with the *S* instructed to choose the test items that was the same as the previously presented item.

The item presented could be a nonsense syllable, a word, a tone, a line length, etc., permitting one to determine modality-specific deficits in the memory of any group of handicapped children.

Furthermore, a list of items could be presented during learning with a test of only one of those items after the retention interval. Such a procedure is often referred to as a probe design, but the probe technique can easily be combined with the three-phase (study-test) technique.

The interpolated task need not be backward counting by threes. This would often be too difficult for a handicapped child. In studying the memory of a speech-impaired individual, Shallice and Warrington (1970) used forward counting by ones. Any interpolated activity can be used, including learning more items from a different category or even learning more items of the same category as that presented during the learning phase of the experiment.

There is considerable flexibility in this paradigm, but a little thought makes it obvious that the paradigm is unsuited for the study of memory over very long intervals (hours, days, years). One replication of one condition would take a considerable period of time, and to achieve 50 or 100 replications of several long delays with this technique would be out of the question.

However, for experimental studies of memory deficits over retention intervals from zero seconds to 2 minutes, a single-element or probe three-phase design should be considered first (along with the two-phase probe design to be discussed later). There are many reasons for choosing such a three-phase design deriving from the lack of confounding of the conditions for learning retention and usage. For example, a memory span task (with digits, letters, words, blocks, pictures, etc.) provides one measure which is jointly determined in some unknown way by both acquisition and storage processes, as well as retrieval processes. By contrast, a probe three-phase memory design minimizes the problems of retrieval strategy by requiring retrieval of only a single item. Furthermore, by employing a variety of different retention intervals, one can separately determine the slope and intercept of the retention function. The intercept (measured at zero or some short delay after learning) provides an assessment of the initial degree of learning, and the slope of the retention function provides a measure of the forgetting rate. Furthermore, the design can reveal the separate contribution of short-term and long-term components of the total memory trace (e.g., Waugh and Norman, 1965). A long-term memory component shows up in the form of a relatively flat asymptote of memory performance which is usually reached after a 20 or 30 sec retention interval. One is obviously in a superior position to assess the precise nature of any memory deficit in a group of handicapped children, if he can determine separately the contributions of short-term and long-term memory and whether any memory deficit is in initial degree of learning or subsequent retention (the form of the retention function or its decay rate).

Ordered Recall (Memory Span). If a list of items is presented once or several times possibly followed by a delay interval, followed by a test of the *S*'s ability to recall the entire list of items in the corrrect order, then the paradigm falls within the general category of a study-test paradigm. A short-term memory span test is one primary example of this paradigm, though usually there is no appreciable delay interval.

If many elements are presented in the list to be learned, then a relatively larger proportion of the retention phase may be occurring during the learning period than is the case for the "single" element paradigm. This portion of the retention phase is occurring under conditions that are the same as the conditions for the learning phase, and, therefore, this portion of the retention phase is not independently manipulable.

Furthermore, when many elements are required to be retrieved in the usage (test) period, then the conditions depend upon the speed and manner in which the *S* retrieves previous memory traces. This frustrates experimental control of the test phase to some extent and can make precise analysis of the results considerably more difficult. For example, in a memory span test, if the *S* fails to recall the fifth item in the list, it is difficult to say to

what extent one can then assess the strength of any association or connection to the sixth item in the list, given that *S* failed to recall the fifth item.

When there is no delay interval between the learning and test periods (as in an immediate memory span test), one is completely unable to manipulate the retention phase independently of the learning and test phases. All of the losses that are occurring in retention of an item are presumably occurring during presentation of subsequent items during the learning period or during retrieval of prior items during the test period.

Tests of immediate memory span badly confound the three phases of the memory process, and, in many instances, investigations of short-term memory deficits in handicapped children should employ newer methods. The memory span test does have two compensating advantages which may more than compensate for its deficiencies for certain purposes. First, the test provides an overall measure of short-term memory performance. If a particular investigation is not interested in making finer distinctions regarding the acquisition, storage, or retrieval locus of any deficit, then a memory-span test may be the ideal instrument. Second, the memory span test is a much more efficient (less time-consuming) memory test to administer than the single-element or probe three-phase design or the two-phase probe design. There are two principal reasons for this: (a) the time per trial is usually less because there is no delay interpolated between learning and test and (b) the subject makes many memory responses on each trial as opposed to a single one with the newer procedure. Finally, memory span tests are less complex and more familiar to the subjects, requiring less instructional time and ingenuity, as a consequence.

Free Recall. This paradigm is similar to the previous one, except that during the test period the *S* need not recall the items in their correct order, but is simply scored on how many items he recalls irrespective of order. All of the preceding comments apply. In addition, one has no control over the order in which the *S* attempts to recall the items in the lists, and there is opportunity for considerable variation in the degree to which the *S* attempts to recall the last items first versus the first items, etc. Differences between different conditions may result from their inducing different strategies during the recall phase, as well as, or instead of, differences during the learning or retention phases.

By the same token, free recall has advantages for the study of learning and retrieval strategies such as clustering of words that are associatively related (e.g., Bousfield, 1953 and 1961; Cofer, 1965; Deese, 1961 and 1962). If one suspects that coding strategy deficits play an important role in the learning problems of any group of handicapped children, then free recall may provide a useful vehicle for the assessment of such coding strategy deficits.

Study-Test Probe. This paradigm involves presenting a list of items or a list of pairs of items, followed by a retention interval, followed by multiple probe tests of the items or pairs in the previous list. If the learned list consists of items, then during the test period the *S* will be given a series of items, some of which were previously presented and some not, and the *S* is to recognize the items that were previously presented. If the list consists of pairs, either a recognition test or a recall test is possible. In a recall test, the *S* is given one member of the pair and asked to recall the other member. In a recognition test, the *S* is given a pair of items and asked to decide whether the pair occurred as a pair in the previous list. In a pure test of order (associative) recognition memory, incorrect pairs would consist of items that had both been included in the previous list but not together as a pair.

This paradigm is especially useful in the study of long-term memory, because it permits one to present a very large number of items during the learning period and have the delay intervals for all of the items occurring simultaneously. This permits one to develop a reasonably large sample size for individual *S*'s in the study of long-term memory. If one is not concerned about the possible complications involved in averaging results over a large number of different *S*'s, then other paradigms can be used to study really long-term memory

(hours, days, years). However, for the study of long-term memory in individual *S*'s, the study-test probe paradigm is virtually essential.

Under conditions where the retention interval is long in comparison to the time involved in the learning and test period, it is reasonable to assume that the conditions obtaining during the retention interval are the conditions affecting storage and neglect the small contributions to the storage phase occurring during the learning and test phases of the experiment. The use of probe (cue) techniques during the test period eliminates many of the uncertainties and complications involved in the previously discussed multiple recall techniques.

Two-Phase Probe Paradigms

Probe Recall. Two-phase probe recall involves presenting a list of items, followed immediately by a test period in which a single item is presented and the *S* is required to recall the item that followed it in the preceding list. Alternatively, one could present a list of paired associates followed by one of the members of the pair with the *S* required to recall the other member of the pair. The important thing about the two-phase technique is that no time elapses between the learning and test periods. Thus, all of the retention phase is occurring during the learning period, since no separate retention period exists, and only a single trace is tested for recall.

Two-Phase Probe Recognition. This paradigm is the same as the preceding one expect that, following presentation of the list of items or pairs an item or pair is presented for a recognition test. All of the same comments apply.

Two-phase probe paradigms have proved to be especially useful in the study of short-term memory, because: (a) the paradigm is optimal for obtaining a pure short-term memory trace with no long-term memory component, and (b) the fastest rates of decay of the short-term memory trace have been obtained using this paradigm. Using other paradigms, it is extremely difficult to eliminate long-term memory components (asymptotes) from the study of short-term memory. If one is interested in testing primarily for the presence of a short-term memory deficit in a group of handicapped children, then the two-phase paradigm is ideal. It provides separate measure of both the degree of learning in short-term memory (assessed by performance on the terminal item or near-terminal items in the list) and decay rate (assessed by the slope of the retention function).

To obtain simple exponentially decaying short-term memory traces, it is necessary to plot the results in terms of discriminability (d' units—see Wickelgren and Norman, 1966). Furthermore, it is necessary carefully to instruct subjects not to rehearse previous items in the list, concentrating attention only on the currently presented item at all times. Such nonrehearsal instructions are critical for eliminating most of the "primacy" effects in short-term memory for serial lists. It may be more difficult to instructionally control the rehearsal strategies of less mature or less verbal individuals. However, it is fortunate that such subjects typically engage in less rehearsal and show less primacy as a result (e.g., Bernbach, 1967). Whether or not nonrehearsal instructions are given, rehearsal is discouraged by a fast rate of presentation. Rates of presentation faster than three or four words per sec. virtually eliminate rehearsal, even in the absence of nonrehearsal instructions. When the two-phase probe paradigm is used in conjunction with nonrehearsal instructions and/or fast rates of presentation, and the results are plotted in log d' units as a function of retention interval, then one can separately determine whether any short-term memory deficit is in degree of learning or rate of decay. Alternatively, one might discover for a certain group of handicapped children that their short-term memory functions were of an entirely different form from that found for normal subjects in the same situations.

Continuous Memory Paradigms

Continuous Recognition. Shepard and Teghtsoonian (1961) developed an extremely efficient technique for the study of "intermediate-term memory" (time intervals of 10's of seconds, minutes or hours): An item is presented and a *S* decides "yes-or-no" as to whether the item had occurred previously in the list, then he encounters the next item and makes the same decision, and so on. Each item is therefore a new item to be learned, a delay-

filling item, and a test item. All of the three operational phases of memory are confounded together, which certainly can cause some difficulties in interpreting the results. For example, when one manipulates the rate of presentation under a continuous recognition paradigm, one is simultaneously manipulating the study time, the density of packing interfering items in the retention interval, and the retrieval time.

There are practical reasons why the continuous design is extremely useful in the study of memory for retention intervals from tens of seconds to a few hours. The reasons are basically that these time intervals are too long for use of the single-element three-phase paradigm, but a little too short for easy application of the study-test probe paradigm. However, the latter paradigm can be used to obtain converging evidence on the interpretations of results obtained using the continuous technique.

Continuous Recall. A slight modification of the continuous recognition paradigm permits the use of a continuous procedure to study recall. One presents a pair of items to be learned for a certain time period, followed by presentation of a single item with the *S* being required to recall the other member of the pair, followed by another learning pair and then a test pair, etc. (e.g., Atkinson, Brelsford, and Shiffrin, 1967). Such a procedure, though continuous, does not completely confound all of the phases of memory. The time and conditions under the learning portion of each trial can be manipulated independently of the time and other conditions of the test portion of each trial.

Continuous paradigms are extremely efficient. They generate an enormous amount of data in a single session. When contact with subjects is limited to a single session or few sessions and one is interested in assessing long-term memory performance over delays from 10's of seconds to 10's of minutes or hours, then the technique may be ideal. However, there will usually be great restrictions on the session length using children as subjects. This limits the maximum retention interval (which must be less than the total length of the experimental session). To investigate longer intervals, the study-test technique would be required.

Paired Associate Learning. Traditional paired associate learning is actually an example of a continuous recall design. One member of the pair is presented and one is required to attempt to recall the other member of the pair during a certain time interval (e.g., 2 sec). Then one is shown both members of that pair for another time interval. This is followed by the test phase for the next pair and then a learning phase (reinforcement, feedback) for the same pair, etc., until all the pairs in the list have been exhausted. Then there is a delay interval which can be a few seconds in the case of "massed practice" or a few minutes or hours or days or longer in the case of "spaced practice". In the usual paired-associate procedure, the pairs in a list are scrambled between trials. (A trial refers to one pass through all of the pairs in the list.) Thus, retention intervals between the previous presentation of the pair and the subsequent test of it are usually not controlled, except that on the average they will be determined by the time it takes to go through a single trial. Such a procedure is obviously not very suited to the precise study of retention functions, but it clearly has been found useful in the study of the conditions that affect learning. Retention studies usually begin only after the subject had mastered the list by the paired-associate technique and involve simply waiting different amounts of time prior to testing retention.

Serial Anticipation Learning. A classic method used by Ebbinghaus is to present a list of items one at a time with the *S* required to anticipate the next item on the list during a certain time interval. After that, the item is shown, and the *S* is required to anticipate the next item. This continues until the entire list has been exhausted. Then following a time interval, the *S* goes through the list again in the same manner. Retention intervals are rigidly determined by the rate of presentation and are constant for every item in the list. This confounds the number of items being learned (list length) with the retention interval. Serial anticipation learning is basically a method for studying learning, not a method for studying retention, though obviously retention is inextricably involved in achieving a learning criterion.

Recognition vs. Recall

"Yes-no" recognition memory is probably simpler to analyze theoretically than recall memory. The principal reason for this is that recognition memory can be free from competition effects, while recall memory often cannot be free of such competition effects. When the alternative recall responses come from a small known set (such as single digits or letters) recall must logically consist of a choice based on the competing strengths of all the alternatives. On the other hand, it is logically possible for one's "yes-no" response in a recognition memory test to depend on the strength of the test item alone and be independent of the strengths of any other items. Precisely this independence has been found for "yes-no" recognition memory by Bower and Bostrom (1968) and Wickelgren (1967). This permits one to analyze the decay of strength by a recognition test, independently of the growth of competing associative strengths.

Memory in Children

A number of additional considerations are applicable to the study of memory in young children, normal or handicapped. In the first place the sessions must be relatively short, which means that the amount that can be learned in one session is correspondingly reduced. In paired-associate learning, the list of pairs must be short, perhaps on the order of four or five pairs for a 6-year-old child. The total length of session for a 6-year-old should probably not exceed 20 or 30 minutes, and the shorter the session the better. In addition to the desirability of short total sessions, only relatively short periods of sustained attention can be demanded of a young child. Thus, a continuous learning task longer than 30 minutes may be unreasonable for even normal children below the age of about 8 or 9.

Children are less able to concentrate on the relevant aspects of the situation and ignore extraneous cues (Gollin, 1960). Zeaman and House (1963) interpret their results to indicate that mentally retarded children have particular difficulty in attending to relevant cues. Stevenson and Wright (1966) suggest adapting children to the experimental situation for some minutes before beginning the experiment and discuss a variety of methods of pretraining children to attend to relevant cues.

Children often require special procedures to maintain the proper level of motivation. On the other hand, a child may have a high degree of motivation to interact with the experimenter, but not in the manner required by the experiment. That is to say, the child may have high motivation, but his motivation is inappropriate for the task. It may be necessary to satisfy the child's curiosity and desire to get to know the experimenter, for a short period of time prior to beginning the experiment. On the other hand, the child may be very unmotivated for personal reasons or because the task is difficult or boring. The courses of action in this case include changing the experimental procedure to make it more interesting, make it less difficult or more interesting (e.g., by making a game of it) or introducing social or other types of reinforcement (e.g., M & M's).

The material to be learned must be carefully analyzed for its degree of familiarity to the child. A child has a vastly smaller vocabulary than an adult, so if one is to use familiar words (for which there are a number of advantages) the experimenter must limit himself to a much smaller total vocabulary of items. In general, for young children, concrete objects tend to be good materials for memory experiments, followed by pictures, and then familiar words. Obviously, it is essential to know whether a child can read, since a child who cannot read must necessarily be given auditory rather than visual presentation of verbal material. In some cases, a child may have a word in his spoken repertoire but not yet to be able to read the word, even though he can read simple books (i.e., other words). Finally, a child may be able to read a word, but only at a slower rate than an adult. Thus, it may enhance understanding of the material to read words to children, even when they have in some sense "learned to read." Experiments studying memory span in children of different ages show that auditory presentation is superior to visual presentation, with the difference decreasing with increasing age, and auditory presentation of the material yields less difference in memory span as a function of age than visual presentation (Conway, 1909; Murray and Roberts, 1968).

Many of the differences found in learning or memory as a function of age can be attributed to differences in reading, recoding, rehearsal, or learning-strategy capability, each of which varies sharply as a function of age. Once these factors have been eliminated from a memory experiment it remains to be seen what, if any, differences remain in the acquisition, consolidation, or decay of either short- or long-term memory. Along this line it has been found that a fast rate of presentation will minimize the difference in short-term memory span as a function of age (Murray and Roberts, 1968). Fast rates of presentation presumably minimize the difference between children and adults because they provide less opportunity for rehearsal and recoding at which adults are greatly superior to children. Along the same lines, I have consistently noted that fast rates minimize individual differences in memory span among adults, presumably for the same reason.

Finally, the most important and difficult consideration in studying memory in young children is to provide instructions regarding a memory task that are understandable to the child. In general, I have found that recognition memory instructions are harder for young children to understand than recall instructions. Thus, a memory span test which, from a theoretical viewpoint, is far more complex than a recognition memory task, is vastly easier for a child to understand than a three-phase recognition memory task. This is extremely annoying, but it is a fact that one must live with. Telling a child to repeat what you say is something that, for one reason or another, children understand at a very early age. By contrast, a delayed matching task, which is in essence what "yes-no" recognition memory is, is a higher level concept, which children attain only somewhat later in life.

Along this line, it is my impression that recognition memory for successive auditory material is harder than for either successive or simultaneous visual material. The reason for this is probably that with visual presentation one can instruct the subject regarding the recognition memory task by giving him a simultaneous matching task and following this by delayed matching with increasingly long delays. This is exactly the same procedure that is used to train monkeys to do delayed matching (recognition memory). With successive auditory presentation, it is much more difficult to teach the child what is meant by a match.

Coding

Coding refers to the internal representation in memory of our knowledge of the world and to the processes by which representation is achieved. Coding is concerned with what is learned and how this is represented in memory. The present section will discuss both the obligatory structural (capacity) aspects of coding and the optional (strategy) aspects of coding in memory.

Obligatory structural aspects include such topics as the modalities of memory, the nature of the representation of concepts in these modalities, the associative or non-associative nature of any memory modality, concept learning (the establishment of new internal representatives), etc. Thus, the capacity aspects of coding are concerned with the logical structure of memory; what its components are, and how they are organized into a system.

Let us assume for the moment that all human beings possess certain basic associative-memory and concept-learning processes. Even if the parameters for these basic memory processes are the same for two individuals, the degree to which one uses these processes and the types of associations or concepts formed depend critically on the strategy the individual chooses to adopt. In the investigation of memory capacity, it is desirable to attempt to control these coding strategies, but one can only control them if he has some idea of what they are. Furthermore, these coding (recoding) strategies are of intrinsic interest and any extension of memory principles to everyday learning situations requires one to understand fully the range of strategies open to an individual in learning and memory tasks. Coding strategies include such mechanisms as selective attention, relating current material to previously learned material, verbal mnemonics (such as embedding word pairs in sentences or devising mediators to link both members of a word pair), visual-image mnemonics, representing order information by group and serial position labeling, etc.

The first topic in the coding section will be the issue of the associative vs. nonassociative organization of human conceptual memory. After carefully defining these theoretical alternatives, it will be argued that human conceptual memory, both short term and long term, is associative. As a basic structural feature of the organization of memory, it is not reasonable to imagine that any handicapped individual would have a nonassociative, rather than an associative memory. However, a variety of quantitative features of the associative memory, such as the number of internal representatives, the ease of forming new internal representatives, the number of associations between internal representatives, the ease of forming new associations, or the longevity of associations once formed, etc., might vary as a function of different handicapping conditions. Such quantitative deficits are more properly discussed in conjunction with later sections of the paper, but the theory of associative memory provides perhaps the most important component of our understanding of memory, and so it is appropriate that this be discussed at the outset.

The second topic in the coding section concerns the probable existence of a "chunking" process in human memory. Chunking refers to forming a new internal representative to stand for a conjunction of old internal representatives. This ability to define new internal representatives is extremely crucial for the reduction of interference in an associative memory. It is quite conceivable that some groups of handicapped children are deficient in their ability to form new chunks. Alternatively, mentally retarded or learning disabled children may less often adopt a strategy of forming new chunks or the chunks they do form may be less appropriate to the needs of the situation.

The third topic in the coding section is concept learning. Concept learning is hypothesized to be the result of both the chunking process and the associative memory process. One likely consequence of a deficiency in chunking or associative memory is that the individual has a smaller "vocabulary" (dictionary) of possible concepts to employ in any new learning situation and/or the concepts he has are of less value in coding knowledge of the world.

The fourth topic in the coding section concerns the different possible modalities of memory. The number of modalities of memory with different coding properties is unknown at the present time, but the verbal modality and the visual-spatial modality are most often distinguished. It would probably be a mistake to strictly identify these memory modalities with "corresponding" sensory input modalities, namely verbal memory being auditory memory and visual-spatial memory being visual memory. Obviously, verbal memory can be established via visual input for any individual who can read and, very likely, for everyone who cannot read, as well. Also, it is likely that the same spatial memory modality can receive input from touch and audition, though vision is surely responsible for virtually all such spatial memories. Nevertheless, vision is the primary input modality in spatial memories, and audition is probably the primary input modality for verbal memories, at least in the developmental sense (since normal children learn to speak long before they learn to read). Thus, it would not be surprising if deaf children had deficiencies in verbal (sequential) memory, and it is almost certain that blind children have deficiencies in spatial memory (due to the restriction of appropriate input, even if their spatial memory capacity is unaffected by blindness). Finally, special learning disabilities may arise in some cases from deficiencies at a strictly central (nonsensory) level in the functioning of one memory modality but not of other memory modalities. Correct diagnosis of a specific memory modality deficiency in a handicapped child may indicate that training should be in a manner which will permit storage in an unimpaired memory modality.

The fifth topic in the coding section will be the selective attention process and its role in the minimizing of "irrelevant" (background) context cues in memory performance. It has been suggested by Zeaman and House (1963) that mentally retarded children have particular problems in effective use of the selective attention process. Some types of learning disabilities may also be largely the result of an inability to ignore irrelevant context cues or

an inability to discriminate what is relevant from what is irrelevant. Special training procedures which draw attention to the relevant cues and minimize the attention-getting potential of irrelevant cues may prove extremely successful in training such children.

The sixth and final topic in the coding section is concerned with the role of coding strategies and the employment of previously established cognitive structure in new learning. It is rarely optimal to attempt to learn anything "by rote," that is, simply rehearsing the material over and over again in one's mind, without thinking of any other related concepts or images. Effective learning generally involves encoding the material presented into concepts that will make the appropriate distinctions within one's own cognitive structure, thinking of relations between currently presented material and previous knowledge or using a variety of special mnemonic devices such as embedding material in sentences or visual images. It should be kept in mind that the memory deficiencies of any group of handicapped children are as likely to be due to deficiencies in coding strategy as they are to be due to deficiencies in underlying coding capacity. Very likely, some children with learning disabilities have learning disabilities which are entirely due to poor coding strategy with no deficiencies in underlying coding capacity. If such strategy deficiencies can be identified, then teaching such a child the appropriate learning strategies may completely eliminate the learning disability. A child who has an underlying capacity deficit will very likely have coding strategy deficits as well. The latter deficits may be removable, even though the capacity deficits are not. The result of this should be greatly improved learning performance, despite the absence of any change in underlying coding capacity.

Definition of Associative and Nonassociative Memory

Two basic types of memory structures have been proposed as models for human memory: associative and nonassociative. In an associative memory, each event or concept has a unique or relatively unique internal representative, and internal representatives have different degrees of association to each other depending upon how frequently they have been contiguously activated in the past. An associative memory uses a single element or a small group of elements in the system to represent any concept or set of concepts. When an event occurs that is an example of a particular concept or a signal for a particular concept, the internal representative of that concept is activated. The assumption is that the system allows a more or less direct connection from an event to a single internal representative or a small set of alternative internal representatives. Thus, when the word "dog" is presented today to a person, it activates a particular internal representative in memory, and the same internal representative will be activated by "dog" when "dog" is presented a minute later, an hour later, a day later, a week later, a year later, or 10 years later.

It seems likely that human beings have a small range of alternative representatives for any given event and that furthermore the range of alternative representations is subject to change over a period of time as the individual learns new concepts. This does not basically alter the hypothesis that, at any given time in a person's lifetime, there is a relatively unique internal representative for every concept.

In computer memory terminology, such a memory is referred to as "content-addressable," to distinguish this type of memory from the more ordinary computer memory that is "location-addressable." In a location-addressable memory, all one can do is encode an event in a particular location, and, if the same event should occur later on, one would have to search through all the locations in memory to find the prior occurrences of that same event. In a location-addressable memory, one cannot directly single out the exact location which has a certain concept stored in it. By contrast, in a content-addressable memory, one can simply ask where in the memory has this event been stored previously and single it out in an immediate (parallel-search) manner.

Thus, an important defining property of an associative memory is parsimony of representation of concepts. The parsimony comes in that time is largely irrelevant to defining the internal representative of an event. No matter what time that event occurs, there are relatively unique internal representatives for the con-

cepts cued by the event. So much for the representation of events in the system.

What about the representation of the order of events that have occurred to an individual. In an associative memory, the representation of order is accomplished by having connections (associations) between the internal representatives whose strengths (degrees of connection) are incremented every time two representatives are activated close to each other in time. Although it does not appear to be logically necessary, there does seem to be a close affinity between the content-addressability property of an associative memory and the associative property of an associative memory. Generally speaking, these two properties are taken together to define an associative memory.

By contrast, in a nonassociative memory there is an ordered set of locations (cells, registers, boxes, etc.) into which the internal representative of any event or concept can be coded, and sequences of events or concepts are stored in order in this ordered set of locations. A tape recorder is a good example of a nonassociative memory. As each successive sound occurs, a pattern representing that sound is impressed on a successive portion of the magnetic recording tape. From a hardware point of view, virtually all computer memories are also nonassociative, though with suitable programing, an associative memory can be simulated.

In a nonassociative memory the representation of an event is by a particular pattern that stands for the event being impressed upon any location in memory. Thus, there can be numerous representations of a single event or concept occurring at different times in the individual's life. These different occurrences of the concept are represented by the same pattern at physically different locations in the memory. In a tape recorder, if one pronounces the same word at different points in time, each pronunciation will impose approximately the same pattern on physically different sections of the tape, for example.

The representation of the order of events in a nonassociative memory is usually assumed to occur by virtue of having a fixed order in which one fills the locations in memory. Thus, a tape recorder fills successive sections of the magnetic tape in a single, linear order preserving the information concerning the order of events. The representation of events in a nonassociative memory is said to be location-addressable, because one can go directly to a particular location, but cannot know what he will find in that location. This applies to both the initial acquisition and the retrieval of a memory trace.

It is possible to assume a kind of hybrid between these extreme forms of associative and nonassociative memories such that the memory is location addressable, but the locations are associated one to another rather than being in a fixed order. However, no especially useful consequence has yet appeared from any such hybrid.

Most human conceptual memory is probably associative. At least one type of human sensory memory, namely, visual, very short-term (sensory) memory (e.g., persistence of vision, afterimages, etc.) is probably nonassociative (Wickelgren and Whitman, 1970). No type of human memory appears to be of the hybrid location-addressable type. Other types of memory found in nature, such as immunological memory or physical memory, fall into neither of these two classes.

Long-Term Memory Is Associative

Existing evidence overwhelmingly favors the hypothesis that long-term memory is associative rather than nonassociative.

First, long-term memory has an enormously large capacity. There must be hundreds of thousands, perhaps millions, of associations between events or concepts stored with reasonable strength in long-term memory. A nonassociative memory with a serial search process would, on the average, have to search half of all the locations in the storage system looking for the cue word in order to come up with the correct response word, say in paired associate learning. A reasonable neurophysiological estimate of the time required to "search" a location might be on the order of 10–100 msec, since a single synaptic delay is on the order of 1 msec. This yields response times for long-term memory that are completely absurd. Of course, acquisition of a memory might be by way of a location-addressable process, but with retrieval proceeding by a content-addressable system (i.e., parallel search).

Such a hybrid memory might get around the present argument and still preserve the location-addressable feature in original learning, while giving-up this feature in retrieval. Nevertheless, it should be noted that a nonassociative system for original learning puts substantial strain on the retrieval system to achieve integration of temporally distributed information concerning identical or similar ideas or concepts. This integration is achieved automatically during learning by an associative storage system. The kind of apparatus required to realize a content-addressable system in retrieval is precisely the same type of apparatus required to realize it in learning, so the hybrid would seem foolish, unless there was some substantial advantage to recording separately every occurrence of every event.

Second, the major advantage of a nonassociative memory is that it could be extremely precise in its temporal resolution of events. A nonassociative memory might tell you the exact time at which different events occurred, and surely would store the exact order, frequency, spacing, etc., of events. A number of recent studies (e.g., Fozard, 1970; Hinrichs, 1970; Hintzman and Block, 1970, 1971; Peterson, 1967; Yntema and Trask, 1963) indicate that human beings do have some ability to judge the recency, temporal ordering, spacing, and frequency of events.

However, to me, the level of this ability seems to be abysmally low in relation to what could be achieved by a nonassociative memory. One often observes that a *S* can recognize nearly perfectly whether an event has occurred in the last hour or so, but has very poor ability to say which of two events occurred first, if they are not too greatly separated in time. It is not at all obvious why a nonassociative memory should have recorded perfectly the existence of the events, but somehow scrambled or otherwise lost the memory for the order of the events, when this seems to be the primary advantage of using a nonassociative storage system in the first place.

Intuitively, it seems that the large majority of all of our factual knowledge about the world (generic memory) is of the form where, although we remember concepts or facts we previously learned, we cannot remember the time or context in which we originally learned them. There are, of course, many exceptions to this where we do remember the time and the context in which we learned certain things, but these seem to be exceptions rather than the rule.

Furthermore, from a teleological viewpoint it is primarily the generic knowledge that is useful for survival and not the more temporally or context-specific knowledge. Thus, an associative memory seems like just the kind of memory that would be extremely efficient for survival.

Third, recall and recognition of learned material varies with the nature of previously or subsequently learned material. That is to say, recall and recognition show interference effects, and the magnitude of these interference effects varies with the similarity between the material.

When a *S* is given the stimulus member A and attempts to recall the response member B of a previously learned A-B pair, he is less likely to recall B when he has previously or subsequently also learned an A-C association than when he has previously or subsequently learned a C-D association. The negative effect of prior learning on the ability to acquire, consolidate, store, or retrieve subsequent learning is termed *proactive interference*. The negative effect of subsequent learning on the ability to consolidate, store, or retrieve prior learning is termed *retroactive interference*. Both proactive and retroactive interference depend upon the similarity of the prior or subsequent learning to the learning that is being tested. Similarity-dependent proactive and retroactive interference is a direct and obvious consequence of an associative memory system. Since the separate occurrences of event A activate the same representative, learning a pair A-B along with a pair A-C could cause each trace to be weaker in storage (storage interference) and could also produce competition, blocking, or other problems at the time of retrieval (retrieval interference).

Similarity-dependent retrieval interference can be explained by a nonassociative memory provided one again assumes that the nonassociative memory has lost perfect ability to distinguish the order of the locations on the tape in which one learned the A-B pair versus the A-C pair. Clearly, if one were required to

retrieve the response to A, and A appeared at two different places on the tape with two different successors, one would have more uncertainty in determining the correct response than if A only appeared with a single concept following it on the tape. Again, however, the nonassociative memory is forced to give up perhaps its most distinguishing feature, precise temporal separation, in order to account for the phenomena.

Storage interference refers to the effect of (usually) subsequent A-C learning to lower the strength of an A-B memory trace. Assessment of storage interference is achieved by using recognition tests rather than recall tests. If one asks an *S* whether or not A-B occurred as a previous pair and characterizes his ability to determine whether A-B occurred as opposed to A-D or some other incorrect pair, there is no logically necessary reason why there should be any competition at the time of retrieval between previously learned A-B and A-C pairs. Furthermore, there is experimental evidence to support the hypothesis that recognition tests avoid this type of retrieval interference (competition), and thus provide purer measures of decay or storage interference (Bower and Bostrom, 1968; Wickelgren, 1967).

Every study with which I am familiar of the similarity dependence of retroactive interference in recognition tests of long-term memory has shown that such storage interference is greater with more similar interpolated materials than with less similar interpolated materials (e.g., Keppel and Zavortink, 1969; McGovern, 1964; Postman, 1965). Storage interference effects are much smaller than retrieval interference effects as evidenced by the fact that the amount of retroactive interference shown in a recognition test is much smaller than the amount shown on a recall test (Postman and Stark, 1969). However the similarity dependence of storage interference in verbal long-term memory is an extremely reliable phenomenon, despite its modest size in experimental studies with small amounts of interpolated learning.

Thus, we may regard similarity-dependent storage interference as well established, and its existence is quite difficult to explain with a nonassociative memory. There just does not appear to be any reason why storing A-C in one pair of adjacent locations should cause greater decay of A-B in another pair of locations than should storage of C-D in the prior pair of locations. In an associative memory, it is perfectly reasonable to suppose that the connection capacity of any single internal representative is limited, so that increasing an A-C association will tend to weaken an A-B association. Furthermore, it may well be quite adaptive for the survival of an organism to have forgetting depend upon whether new associations need to be formed to the same internal representatives or not. If an internal representative does not have any new associations that need to be established to it, the old ones might well be allowed to exist for a long time. However, if the contingencies of the world are changing, one might well need to quickly "unlearn" prior associations as well as learn the new associations. An associative memory can achieve such similarity-dependent, storage-interference in a very natural way. A nonassociative memory would have to have some special *ad hoc* device in order to accomplish this objective.

Other arguments for the associative nature of long-term memory and also verbal short-term memory are given in Wickelgren (1964, 1965a, b, & c, 1966a & b, 1967b, in press).

Chunking

In information theory, the amount of information conveyed to a human being by the occurrence of a particular event is greater the greater the number of possible alternative events that could have occurred at that time. Information is equal to $\log_2$ of the number of alternatives, provided each of the alternatives is equally likely to occur *a priori*. It might seem reasonable that the difficulty in remembering a sequence of events would be greater, the greater the information conveyed by the events. That is to say, the difficulty in remembering the events would be greater the greater the number of alternatives that existed for each of the positions in the sequence.

However, as Miller (1956) has argued, the effect of the number of alternatives (information) on short-term memory, for example, are extremely small. Memory span appears to be limited primarily to a certain number of events

or "chunks" and is relatively independent of the amount of information in each chunk.

Thus, one can increase memory span by recoding a sequence of events into a sequence of fewer chunks, with each chunk conveying information concerning the occurrence of several events. Miller cites an experiment by Smith which showed that *S's* could greatly increase their memory span for binary digits (sequences of 1's, and 0's) by learning to recode binary digits into octal digits according to the following rules: 000 = 0; 001 = 1, 010 = 2; 011 = 3; 100 = 4; 101 = 5; 110 = 6; 111 = 7. This recoding scheme maps three events (symbols) into one event (symbol) reducing the number of chunks while preserving all of the information in the original sequence. Memory span almost triples using such a recoding procedure.

Such tripling of the memory span by binary to octal recoding requires considerable practice in learning the recoding system. Furthermore, learning the recoding system would undoubtedly be more difficult, if the new chunks were new concepts rather than already existing concepts (the digits 1 through 8). Nevertheless, it seems quite apparent that human beings possess the ability to find new symbols to stand for long sequences of previously defined symbols, and indeed this practice is used in mathematics and science all the time. The difficulty of learning a list increases with the number of different internal representatives that must be used to encode the list, but people appear to have the ability to define new informationally richer units in which to encode events. This process of defining a new internal representative to be a conjunction of old internal representatives will be called the *chunking* property of human memory, following Miller (1956).

A little thought concerning the previously discussed similarity-dependent interference phenomena indicates why such a chunking process would be an extremely desirable property. Such a process of defining new units to stand for a conjunction of old units would allow one to avoid some otherwise extremely serious associative-interference problems connected with the representation of events by a set of attribute representatives. Attributes would necessarily be present in many different events, and in an associative memory each of these attributes would have to be associated to the various attributes of contiguous events in hundreds of different event-complexes of attributes. Such a process would produce an enormous degree of A-B, A-C type retrieval and storage interference when the A's, B's, and C's are considered to be the component attributes of hundreds or thousands of different events. The chunking process allows one to achieve as great a difference in representation of highly similar concepts as is desired.

Phenomena consistent with a chunking process abound in the area of human memory. First, there are the sometimes dramatic improvements in memorizing efficiency that can be achieved by learning a recoding scheme to reduce the number of chunks that must be learned (e.g., Miller, 1956).

Second, it is well established that sentences are easier to remember in both short- and long-term memory than comparably long lists of random words (Coleman, 1963; Marks and Jack, 1952; Miller and Selfridge, 1950). Indeed, these studies have shown a gradual increase in the ease of memorizing material as one increases the degree of approximation of a random sequence of words to a grammatical English sentence. This has been considered to reflect the fact that we have higher order units for a sequence of several words when the words are arranged in certain grammatical phrases, but not when the words are randomly ordered. There is, of course, considerable uncertainty regarding the degree to which we have previously established a single internal representative for an entire phrase of two or more words in the English language. Some of the superiority of sentence memory over memory for random words might consist of strong associations among the component concepts in a sentence. However, it seems likely that many of the phrases that occur in sentences occur repeatedly and, if we had a chunking process, each familiar phrase could be represented by a single unit in the system, facilitating memory for any sentence that involved that phrase.

Third, there is considerable evidence to support the proposition that when a subject attempts to learn either a serial list or a list of paired associates there are two different phases of the list learning process. First, there is the

phase of response learning or unit (response) integration and, second, there is the period in which the stimuli are associated to the "integrated" responses (e.g., Underwood and Schulz, 1960). The unit integration phase is short or nonexistent for meaningful words, which presumably already exist as concepts in the system. By contrast, when the materials in the list are nonsense syllables or consonant trigrams, the response learning phase can be quite long, reflecting the fact that these units are not already defined by single internal representatives in the memory system. The definition of a single internal representative for each unit being learned in the list is considered to be an important first step in establishing a high level of association between units that will survive the effects of both intralist and interlist interference.

Concept Learning

A concept can be defined to be a disjunction of a variety of conjunctions of attributes. Thus, the printed word "dog," the spoken word "dog," the sight of a dog, the sound of a dog barking, etc., can all elicit the same concept representative. Similarly, the sight of a dog from various perspectives and the sight of dogs of different species with very different physical properties can all elicit the same general concept of a dog. It is hopeless to think that one can find some common set of physical attributes in all of the adequate cues for the concept "dog." Thus, it is erroneous to define concepts in a manner that requires abstraction of common properties.

It would probably be much too difficult by virtue of associative interference to associate sets of attributes one to another, without first chunking each set of attributes and defining a new internal representative to stand for the chunk. For this reason, it seems likely that one stage in human concept learning is to chunk each set of attributes that constitutes a set of sufficient cues for the elicitation of the concept. After two or more chunks have been defined, if these chunks are sufficient cues for the elicitation of the same concept, then these chunks are associated to each other (or to some higher level concept representative). This association of chunks is the second stage of concept learning.

According to this theory, children should learn very specific concepts at first, where by "specific concepts" is meant concepts which are elicited by only one or a few sets of cues. Only gradually would a child learn all of the different sets of cues that are considered sufficient by adults to elicit the concept (i.e., learn "general" concepts). The contrary argument is often made that children learn "overgeneralized" concepts initially and only later learn to apply concepts to the right specific instances. Examples are cited that a child may call every man "father." Saltz (1971) cites a number of studies that indicate that the overgeneralization position on concept learning is not correct and that children in fact learn much too specialized concepts at first.

However, the terms "specialized" and "overgeneralized" are usually not very clearly defined, so it is difficult to evaluate the present hypothesis with the previous findings. Usually, the terms "specialized" and "generalized" refer to *logical* (set-theoretic) generality, not *psychological* generality in the sense proposed here. Logical generality is a property of "dictionary definitions" of concepts. In this sense, the concept "dog" is more general than the concept "Saint Bernard dog" and less general than the concept "living thing." Clearly, the average child learns the concept "dog" before he learns either of these other two concepts. It is doubtful that any important psychological principle can be formulated regarding the degree of *logical* generality of concepts learned initially by children. With the currently proposed *psychological* definition of concepts as disjunctions of chunks, it is quite plausible that concepts develop increasing generality in the sense of having more and more chunk representatives associated to them (that is more and more sets of cues to elicit the same concept representative).

In summary, concept learning is considered to be composed of two basic learning processes: *chunking* a set of attributes to define a new internal representative and *association* of chunks one to another. The first establishes a conjunction of attributes. The second establishes a disjunction of these conjunctions. This theory of concept learning and speculations regarding possible neural mechanisms to achieve

it are presented in more detail in Wickelgren (1969).

Concept Learning Deficits. It is possible that many or all mentally retarded individuals may suffer to a large extent from an inability to form new concepts via deficits in the chunking process or deficits of the associative memory process. The simplest explanation might simply be that they have fewer free internal representatives available to become specified to stand for new concepts, but there are many alternative physiological difficulties that could impair concept learning. Whatever the reasons for this, the consequences for learning and memory of learning fewer concepts are that the encoding of anything one wishes to learn will be (on the average) less distinctive from other materials coded into memory. This results in more retrieval and storage interference. For mentally retarded individuals, it may be very important to spend considerable time at the concept learning process, that is to say, learning the vocabulary in any area of knowledge, before proceeding to learn facts and principles (statements, propositions) involving those concepts. It could turn out that the learning of facts and principles would be almost normal in such an individual after sufficient time has been spent to teach him the basic concepts of the area.

Again, normal children learn many concepts that are later replaced by better concepts or are of no value to them in what they do later on. Although it is more costly and limits the choice of the handicapped person somewhat to decide in advance exactly what concepts he should learn, this can greatly increase the efficiency of concept learning for a person with this type of handicap.

Modalities of Memory

For a while some people thought that memory might be in a modality of its own, separate from the various sensory, motor, and cognitive modalities. Lesion studies have failed completely to discover an area of the brain that is the repository of memories, which is not also intimately concerned with perceptual, motor, or cognitive aspects of functioning. There is one exception to this general statement; namely, a few human neurological patients have a rather specific loss of the ability to *consolidate* new long-term memories, while their old long-term memories remain relatively intact, and other aspects of sensory, motor, and cognitive functioning are well preserved (Scoville and Milner, 1957; Milner, 1966). Thus, there may be a special area of the brain concerned largely or exclusively with a consolidation process. However, the actual storage of both long-term and short-term memories must be considered to be distributed throughout the various sensory, motor, and cognitive modalities of the brain.

It is difficult at present to specify the different modalities of the brain that have memory capacities (memory modalities). It is generally thought that visual-spatial memory is a somewhat separate modality from verbal-semantic memory. At the same time, verbal-semantic memory is often considered to be a separate modality from verbal-phonetic memory. There is evidence to support a general distinction between verbal versus various nonverbal memory modalities in studies of the asymmetry of the two hemispheres of the brain. Brain damage to the left hemisphere appears to affect various aspects of verbal cognitive functioning, including verbal memory, more than brain damage to the right hemisphere (Milner, 1966). By contrast, damage to the right hemisphere affects a variety of nonverbal tasks, including memory, more seriously than brain damage to the left hemisphere (Milner, 1966).

It may be that there is considerable similarity in the dynamic and retrieval properties of memory across different modalities, with the only differences being in the attribute or dimension systems used to encode memories, but the differences may be more extensive. Comparison of long-term memory for meaningful verbal and pictorial material indicates rather similar retention functions and rates of loss of memory in both cases. The most striking dynamic distinction between verbal and visual-spatial memory appears to be in the speed of acquisition and consolidation. A rather sizable long-term memory trace for a picture can be established within a few seconds (2–5 seconds). For example of such studies of visual long-term recognition memories see Shepard (1967) and Nickerson (1968). To achieve comparable levels of learning in say a verbal paired associate learning task requires

usually many trials of several seconds each (e.g., Nelson, 1971). The difference is perhaps not intrinsic to the comparison between visual and verbal modalities. Rather the visual material may be simply much more detailed and redundant than the usual verbal material presented in laboratory learning tasks. A picture may be "worth a thousand words." To achieve comparable levels of memory for verbal material one might have to present an entire paragraph as the "item" being remembered. However, in such a case it would usually take considerably longer to read the entire paragraph than it takes to encode a picture. Thus, because of differences in simultaneous versus sequential input, the visual and verbal modalities may have different speeds of learning.

An interesting study by Paivio and Csapo (1969) provides evidence that the verbal memory modality is specialized to learn and remember sequentially ordered material, while the visual-spatial memory modality is specialized to learn and remember nonsequential material. One might speculate that the type of nonsequential material for which the visual memory modality is ideally suited is memory for a large number of simultaneously presented attributes (as in a picture).

Visual sensory input is surely primary for the visual-spatial modality, and auditory input is at least developmentally primary in establishing traces in the verbal modality. However, it is surely a mistake to identify these modalities of memory with the "corresponding" sensory modalities. In the first place, for adults who can read, it is clear that much long-term verbal memory is established by way of visual sensory input. Whether or not this occurs to some extent as a result of an individual "saying the words to himself" is largely irrelevant to this observation. Even in short-term memory for visually presented verbal materials, there is often storage in a verbal phonetic modality, instead of, or in addition to, storage in visual memory (Conrad, 1964). In the second place, auditory sensory input apparently can lead to storage in the visual-spatial memory modality. Paivio, Bower, and their associates have repeatedly shown that the establishment of long-term memory traces in paired-associate and other learning tasks is facilitated by using words with high visual imagery ratings (see Paivio and Okovita, 1971 for a study that used auditory presentation). The visual-spatial and verbal memory modalities are clearly cognitive, rather than sensory, memory modalities, and, as such, they can receive input from several sensory modalities.

Modality Deficits. As noted above, the left hemisphere of the brain seems to be specialized for the representation of verbal material and the right hemisphere of the brain specialized for a variety of nonverbal information processing (especially visual-spatial material). At the present time, it is certainly not clear how many different nonverbal modalities one ought to distinguish, nor is it clear how many verbal modalities or levels of a verbal modality one ought to distinguish. However, it is clear that many individuals suffer moderate to severe deficits in a particular modality, without showing any deficits, or even showing a partially compensating superiority, in other modalities of functioning.

One good example of the dissociation of performance in different modalities is provided by some recent studies of short-term memory in handicapped persons. Deaf, severely hearing impaired, and speech impaired *S*'s typically perform more poorly than normal *S*'s on tasks considered to be facilitated by auditory imagery (Hartman and Elliott, 1965) and on memory span tests or other tests of verbal (sequential) short-term memory (Blair, 1957; Olsson and Furth, 1966; Withrow, 1968–69). However, when material is presented that even normal *S*'s might be expected to code visually rather than verbally, deaf *S*'s can perform as well as or even better than normal *S*'s (Blair, 1966; Olsson and Furth, 1966; Ross, 1969; Withrow, 1968–69).

The remarkable patient of Warrington and Shallice (1969) demonstrates a memory span of about one and a half digits when the digits are sequentially presented at a rate of one digit per 500 msec. However, the same *S* can achieve a memory span of about 3.5 digits when the digits are presented simultaneously tachistoscopically for only 250 msec. Such a striking discrepancy between verbal sequential short-term memory and visual simultaneous short-term memory indicates clearly that memory impairments can be extremely selective with regard to modality.

Paivio and Okovita (1971) studied paired-associate learning by congenitally blind vs. sighted subjects of nouns rated high or low in auditory or visual imagery. The long-term memory performance of blind subjects was facilitated by auditory, but not by visual, imagery, whereas the reverse effect was obtained for sighted subjects.

Evidence for the need to dissociate conceptual memory from sensory-motor memory has been obtained from studies on the famous patient H. M. of Scoville and Milner (1957). Corkin (1965 and 1968) has shown that H. M. shows substantial capacity for motor and sensory motor learning in a variety of tasks such as rotary pursuit, bimanual tracking, and tapping. His substantial improvements from session to session in motor and sensory-motor performance occurred despite the fact that H. M.'s conceptual memory was so poor that he did not even remember being in the same experimental situation from one session to the next. Some types of visual-perceptual memory may also be preserved in patients who have nearly complete inability to consolidate new conceptual memories (Warrington and Weiskrantz, 1968; Milner, Corkin, and Teuber, 1968).

It is a testimony to the extraordinary flexibility of the human mind, that deficits in one modality can often be partially overcome by use of a different modality. For example, there is now considerable evidence to indicate that deaf and hearing impaired *S*'s frequently make use of visual or dactylic (finger-spelling) coding to remember sequentially presented verbal material that normal *S*'s encode phonetically (Conrad, 1970; Locke and Locke, 1971), though some deaf *S*'s who have high speech quality appear to employ articulatory coding in verbal short-term memory (Conrad, 1970). Depending upon the modality in which the *S* encodes material to be learned, some types of material are easier or more difficult to learn (Conrad, 1970; Allen, 1971). Elliott and Vegely (1969) suggest that rewarded training may be helpful for hearing-impaired children in sequential-processing and memory tasks.

Knowledge of the modalities of encoding used by a particular handicapped child in a particular task would be of considerable benefit in determining how to present the material and how rapid to expect learning to be. The two principal methods of assessing the type of coding used by a *S* in a task are: (a) to determine whether errors tend to be phonetically similar, visually similar, dactylically similar, etc. and (b) to determine whether interference and/or facilitation in learning and memory varies with the phonetic, visual, dactylic similarity of the material. The type of similarity that affects errors and speed of learning indicates the encoding modality used by the *S* for that type of material.

Selective Attention and Background Context

It is sometimes asserted that cues from the learning context become strongly associated to the material being learned, and the presence or absence of these context cues at the time of retrieval can enhance or depress the memory performance as a result. The underlying assumption is either explicitly or implicitly that the representatives of all potential stimuli in the situation become associated one to another as a result of learning. McGeoch and Irion (1952, pp. 448–451) have stated the case for the importance of context in coding and retrieval from memory in a very detailed manner.

However, close examination of the experimental work cited by McGeoch and Irion and other studies on the effects of "irrelevant" context in learning reveals that only a few studies find significant effects of altering the background context cues from learning to retrieval. Unpublished work of my own has also failed to reveal any significant effect of altering the context on either recall or recognition of Russian-English word pairs. Since some of the alterations in experimental context have been deliberately designed to be as extreme as possible, the negligible or unreliable effects observed argue strongly that "irrelevant" context often plays a rather small role in the coding and retrieval processes of memory.

There is a very good teleological reason for this which can be illustrated by the example of learning to identify a poisonous species of mushroom in the forest. One would hardly want the exact conditions of time, place, and emotional attitude under which one learned to identify the characteristics of the poisonous mushrooom to play any important role in one's

ability to recognize another example of a poisonous mushroom at a different time, place, and emotional context.

The actual psychological mechanisms by which this relative unimportance of context in memory is achieved are probably: (a) selective attention at the time of learning and (b) storage interference processes which selectively weaken whatever associations do get established involving irrelevant context cues.

Selective attention is an important control process determining what gets coded in memory. Besides filtering out the effects of irrelevant background context, selective attention permits each individual to concentrate his limited learning and memory capacity on those principles of greatest use to him. Selective attention is thus a valuable mechanism exerted at the time of acquisition, for providing motivational control of the contents of memory.

Selective Attention Deficits. A child with only a selective attention deficit should be considered to have a special learning disability. Such a child finds it difficult to concentrate on certain aspects of a situation and selectively ignore other aspects. Alternatively, the child may be selectively attending, but does not very adequately distinguish what is really relevant and what is irrelevant. The latter type of selective attention deficit suggests either that the child has a general mental deficiency or else that he has not received proper instruction that will permit him to discriminate relevant from irrelevant aspects of a learning situation. Zeaman and House (1963) in their research on discrimination learning in mentally retarded children concluded that selective attention deficits are a major feature of the learning deficits of retardates. They suggest that successful training of retarded children should very carefully direct the child's attention to the relevant cues in each situation.

Theoretically, there are two classes of approaches to counteracting selective attention deficits on a short-term basis. First, one can attempt to minimize the presence of distracting stimuli or the attention-getting value of these stimuli. Second, one can attempt to enhance the attention-getting value of the relevant stimuli. At an immediate sensory level, it is the changing or novel stimulus and the more intense or otherwise stressed stimulus that has the greatest attention-getting value. At a higher cognitive level, the interest of the material to the *S* is critical for maintaining attention to the relevant stimuli for any considerable period of time. These principles apply both to the minimizing of the attention-getting value of irrelevant stimuli and the maximizing of the attention-getting value of relevant stimuli.

On a longer term basis, it is perhaps possible to train some children with selective-attention deficits to learn to ignore distractions and concentrate on relevant stimuli. This is particularly true if the selective-attention deficit is a strategy deficit rather than a capacity deficit. Individuals appear to differ considerably in the degree to which they control what they learn on the basis of their goals via the selective attention mechanism. In deciding on a course of training in regard to selective attention deficits, it seems important to discriminate whether the problem is due to: (a) a poor strategy in the use of the selective attention mechanism, or (b) a capacity limitation in the functioning of the selective attention mechanism when attempts are made to employ it (i.e., the subject is attempting to "concentrate").

Coding Strategy and Structure in Learning

Most learning in adults involves embedding new material in a rich already existent cognitive structure of previously learned material. Even so-called laboratory "rote" learning tasks have been shown to involve substantial use of cognitive structure in the learning by experimental *S*'s. In memorizing word pairs, *S*'s attempt to: (a) embed the words in a phrase or sentence, (b) think of some other mediating concept that is strongly associated to both the stimulus and response members of the pair, (c) think of a single visual image in which to embed both members of the pair, etc. Even in learning nonsense syllables, *S*'s try to make words out of the syllables and then go through the same processes previously mentioned for words (e.g., Prytulak, 1971).

When phrases are provided in which to embed the members of a word pair, learning is facilitated even when this phrase context is not presented along with the stimulus member of the word pair at the time of recall (e.g., Ep-

stein, Rock, and Zuckerman, 1960). *S* or *E* generated natural language mediators (e.g., A (Apple)-Pie) for various paired associates also assist recall even when the mediators are not supplied by *E* at the time of recall (e.g., Montagne, Adams, and Kiess, 1966; Schwartz, 1971). Likewise, supplying the members of a pair in the form of a unitary visual image improves recall of one member of the pair given the other member. This occurs even though the recall test involves a decomposition of the picture into parts, which might be expected to depress memory by comparison to a condition in which the parts of the picture are presented as two separate visual images in both learning and test (Epstein, Rock, and Zuckerman, 1960; Asch, Ceraso, and Heimer, 1960). Word pairs that have higher probabilities of spontaneously evoking natural language mediators have higher probabilities of being remembered (Walker, Montague, and Wearing, 1970). Likewise, word pairs that have high probabilities of evoking visual images have high probabilities of being remembered (Paivio, 1969). These studies show the overwhelming importance of the ability to embed newly learned material into a previously learned cognitive structure as an aid to both learning and retention.

It seems likely that learning in a young child involves much less use of previously existing cognitive structures, for the simple reason that a child has less previously learned cognitive structure. Thus, for example, memory for the meaning of spoken or written words and the ability to pronounce an arbitrary sequence of sounds to make a given word is likely to be more or less "rote" learning process. There is a completely arbitrary connection between a sound or spelling of a word and its meaning. Likewise, there is a completely arbitrary association between the meaning of a concept and the sequence of articulatory gestures necessary to speak a word signifying that concept. Thus, there would seem to be literally no basis for anything other than a rote learning process involved in such elementary learning of the lexicon of a language.

As a child grows older, however, the nature of the things he is learning indicates a larger role for cognitive structure. In addition, the child has more cognitive structure to employ. Thus, it seems entirely reasonable that the degree of influence of prior cognitive structure on new learning should increase as a individual grows from childhood to adulthood.

Contrary to what one might suspect on the basis of proactive and retroactive interference, the ability to learn most types of material appears to increase steadily with increasing age from childhood to adulthood. Thus, the net positive advantages of having a rich prior cognitive structure must outweigh the interference effects. We conclude this without in any way detracting from the reality of both retrieval and storage interference phenomena in memory.

A rather different type of coding which is very helpful in sequential short-term memory for visual material is the use of a verbal label for each visual stimulus (picture). Instructing and training children to attach verbal labels to pictures in sequential short-term memory tasks has facilitated short-term memory performance in children, making them more nearly equivalent to adults in performance on such tasks (Bernbach, 1967; Kingsley and Hagen, 1969). As mentioned previously, the verbal modality appears to be specialized for sequential memory whereas visual-spatial memory is specialized for simultaneous memory. Thus, when sequential memory is required for pictorial material, it is advantageous to recode the pictures into a sequence of verbal labels. The degree to which the subject employs this strategy will have a substantial effect on his memory performance in this type of tasks.

Coding Strategy Deficits. The associative nature of memory implies that what is stored consists of associations between concepts that were thought of in close temporal continguity. A normal individual, when learning some new material, thinks to some extent about relations to other previously learned material and forms a whole host of associations, not just the associations based on what was presented to him. If a handicapped individual has coding strategy deficits, he may form far fewer of these associations based on logical deductions at the time of learning. Even normal individuals are often quite deficient at encoding the relationships between current material and previously learned material and may require that these

relationships be pointed out quite explicitly during learning. However, it may be critical to point out such relations to a mentally retarded individual with a coding strategy deficit, for example.

Although the notion that memory is associative has been around since the British associationists in the 17th and 18th centuries, and even possibly since Aristotle, popular understanding still too often considers learning to consist of dropping some event into a place in memory. As previously indicated, memory consists of storing connections or associations between the representatives of different events or concepts. Putting a fact into a person's mind in such a way that he can repeat it shortly thereafter, in no way guarantees that he connects this fact to everything that the teacher regards it as logically related to.

I have known teachers to be shocked when they give an examination question that tests knowledge of some material presented in the course in response to slightly different cues than it was originally presented with, only to discover that virtually none of the students recall the material. From this they erroneously concluded that the students remembered nothing about the material. Such conclusions demonstrate ignorance of the principle that memory is associative. The students' failure to perform on such a question very often reflects their lack of ability to see the relationship between the material and the cues presented on the test question. To achieve such generalization of knowledge to all of the appropriate conditions where it is applicable, it is frequently necessary to explicitly teach those relations one wishes the student to see. With normally intelligent *S*'s, we rely to a larger extent than is possible for some types of handicapped children on the ability of the learner to draw logical deductions from the material given and see relationships to other previously stored knowledge.

Dynamics

Dynamics refers to the time course of the quantitative properties of different traces through the acquisition, consolidation, storage, and retrieval phases of the memory process. Developing a theory of memory dynamics appears to require three types of decisions. The first decision concerns the types of quantitative properties to be assigned to memory traces. For instance, will each trace be characterized by a continuous or a discrete (finite-state) variable? If continuous, will the fundamental trace be characterized by a response probability or by a trace strength which is linked to response probabilities by the retrieval rules? Does the memory trace need to be characterized by a vector or a matrix of two or more real variables, as opposed to a single variable?

The second decision concerns the number of memory traces that have different dynamics, that is, different laws of acquisition, consolidation, storage, or retrieval of memory. At present, it is widely believed that two dynamically different traces, short-term memory and long-term memory, will suffice. However, within the area of experimental psychology, short-term memory is usually considered to persist for a period of seconds or 10's of seconds following learning, with long-term memory being responsible for retention after delays of 10's of seconds, minutes, hours, days, weeks, months, and years. On the other hand, in studies of the neural basis of learning, it is usually assumed that short-term memory is responsible for retention up to delays of a few hours, with long-term memory taking over only after that. This enormous discrepancy suggests the possibility that there are three dynamically different traces: short-term memory, intermediate-term memory, and long-term memory.

The third decision concerns the number of different dynamic phases of the memory trace (such as acquisition, consolidation, storage, and retrieval) and the laws of operation of these dynamic phases. This is really the major area of experimental work, since characterizing the laws of the different phases of a memory trace is the primary means of validating theoretical decisions regarding both the quantitative properties of memory traces and the number of dynamically different traces. Within the continuous strength formulation of memory (that I have adopted), characterizing the dynamical law for a phase requires one to develop a function or several functions characterizing the form of the function which relates properties of the memory trace to the passage of time within each phase. The function or

functions describing a phase will necessarily involve a small number of parameters (degree of learning, rate of decay, rate of consolidation, etc.) and there should be additional laws characterizing the values of these parameters as a function of the major experimental conditions that affect them. The view expounded here will be that the phases are not overlapping in time and that the output of the prior phase constitutes the input for the subsequent phase. However, alternative assumptions involving some degree of temporal overlap between the phases have not been very fully investigated.

The present theory of memory dynamics suggests the possibility that children with certain types of handicaps might be impaired in short-term memory but not in long-term memory and vice versa for children with other handicaps. There do appear to be individuals who have very large deficits in long-term memory with little or no deficit in short-term memory (e.g., Milner, 1966). It may also be possible to have the reverse (a deficit in short-term memory with little or no deficit in long-term memory), as in the patient of Warrington and Shallice (1969), but this is less well established as a dynamical deficit as opposed to a modality deficit.

Also, the present theory suggests the possibility that certain phases of the memory process might be selectively impaired in certain individuals with no impairment to the functioning of other phases. Evidence for this already exists as well. The patient H. M. studied by Milner (1966) shows a severe deficit in the acquisition-consolidation of new long-term memory traces but it is apparently unimpaired in the retrieval of previously established long-term memories, and unpublished data of my own indicate that he may be unimpaired in the storage of what little long-term memory he can now acquire and consolidate. Selective deficits in the storage phase with little or no deficit in the acquisition and consolidation phases are also possible. There is considerable evidence that decreasing arousal during learning, regardless of the cause, produces a faster rate of decay during storage of the long-term memory trace. An individual might have a special learning disability of this type as a result of chronically low arousal. Administration of stimulants or the use of background noise to increase arousal could facilitate retention in individuals with this type of learning disability.

Properties of Memory Traces

I characterize all memory traces by a continuous, real-value variable; namely, its *strength*. Greater strength of a memory trace implies greater probability of recall or recognition, but strength is related in a nonlinear manner to the probability of correct recall or recognition (see Wickelgren and Norman, 1966; Wickelgren, 1968). In addition, it appears to be necessary to assume that long-term memory traces must be characterized by two different dynamic properties: *strength* and *resistance* (see Wickelgren, 1971). During storage, the strength of the long-term memory trace decreases monotonically with trace age, but its resistance to the forces of decay increases monotonically with increasing trace age. No comparable trace resistance property seems to be necessary to characterize short-term memory, and this constitutes one type of indirect evidence for the need to distinguish short-term and long-term memory.

Many studies have been done in the attempt to decide whether memory traces are discrete (all or none) or continuous (incremental). There are serious problems in drawing any definite conclusions from virtually all of these studies. At present, only one type of direct evidence has been shown to be potentially conclusive in rejecting finite-state as opposed to continuous theories; namely, that suggested by Krantz (1969). Using this approach, all that has been shown so far is that short-term recognition memory traces could not be two-valued, but must have some larger number of states or be continuous (Krantz, 1969). At present, the principal means of validating any decision regarding the properties in the memory trace is to determine how simple, valid, and general are the laws of memory that can be formulated within that framework.

Number of Memory Traces

At present, the evidence favors the assumption that there are two dynamically different types of memory traces: namely, short-term memory and long-term memory. Short-term

memory is assumed to be established within a period of fractions of a second and to last for seconds or 10's of seconds, though it can be maintained for a longer time by conscious rehearsal in the case of verbal short-term memory. A potential long-term memory trace may be established in a few seconds, but it requires several sceonds or 10's of seconds thereafter to become consolidated into a usable memory trace. However, long-term memory can persist for hours, days, weeks, or years following acquisition.

There is considerable evidence to support the need for assuming two different memory traces. First, it appears to be necessary to assume two component memory traces in order to account for the form of the retention functions of normal human subjects over delays of zero seconds to 2 minutes following learning (Waugh and Norman, 1965; Wickelgren and Berian, 1971). Second, as previously mentioned, long-term memory requires the resistance property, while short-term memory does not (Wickelgren, 1971). Third, a variety of conditions have a different effect on short-term retention (delays of seconds) than on long-term memory (delays of minutes or longer) such as number and spacing of study trials (Wickelgren, 1970a & b; Wickelgren and Norman, 1971). Fourth, storage interference of short-term memory is similarity-independent (Bower and Bostrom, 1968); Wickelgren, 1967a) while storage interference in long-term memory is similarity-dependent (see coding section). Fifth, certain brain-damaged patients demonstrate normal or nearly normal short-term memory while having little or no ability to consolidate new long-term memory traces (Scoville and Milner, 1957; Milner, 1966).

At present, there is no need to assume the existence of any more conceptual memory traces than these two. That is to say, the psychological properties of memory assessed at retention intervals of a few minutes appear to be the same as the properties of memory assessed at retention intervals of hours, days, weeks, or years. Furthermore, the retention function for intervals from a minute to several years appears to be parsimoniously handled by a single long-term memory trace. Memory over retention intervals less than 10 sec appears to be mediated primarily by short-term memory. Memory over retention intervals between 10 sec and 1 min must be assumed to result from a combination of long-term and short-term memory. I am in complete agreement with Deutsch (1969) that the physiological evidence for distinguishing intermediate-term memory (less than 1–3 hr.) from long-term memory is not conclusive.

Phases of Memory

Many investigators of human memory have assumed that there are three theoretical phases of memory: acquisition, storage, and retrieval, corresponding to the three operationally distinguishable phases of a memory experiment: learning, retention, and usage. In the case of short-term memory (retention intervals of a few seconds or 10's of seconds), these three theoretical phases may indeed be sufficient to describe the dynamics of memory. However, in the case of long-term memory, there is some evidence favoring a consolidation phase of the memory process, in addition to, and interpolated between, the acquisition and storage phases.

Acquisition. Acquisition refers to the phase of memory in which an individual is actively (consciously) studying the material to be learned and laying down potential short-term and long-term memory traces. In the case of short-term memory these traces are presumed to be consolidated almost immediately, and there may be no necessity to assume that consolidation is a separate phase from acquisition. In the case of long-term memory, however, these potential memory traces may have to be converted by the consolidation process into usable (retrievable) memory traces. All of the coding and recoding aspects of learning and memory are assumed to take place during the acquisition process. It is here, when an individual is consciously considering the material, that he can think of a mnemonic or visual image to aid in the memory or chunk the separate elements of a list into a single element or meaningful phrase, etc.

Consolidation. The consolidation phase of the memory process is assumed to be an unconscious process in which the potential long-term memory traces, established during acquisition, are converted into a stable usable

form. Note that consolidation is not being thought of as a logical recoding type of change in the memory trace. Any and all recoding is assumed to take place during acquisition and is assumed to be a conscious process. Consolidation is assumed to be a relatively automatic, unconscious process which may be affected by arousal, by certain drugs, etc., in its speed or extent of operation, but nothing during the consolidation process is assumed to change the qualitative (logical) nature of the memory trace established.

Consolidation of long-term memory appears to take place during the first minute after learning, primarily the first 10 to 30 seconds after learning. There are a number of different studies that indicate approximately the same time course for consolidation of long-term memory.

Studies of the retention function for normal human *S*'s invariably indicate that the rapid exponential decay observed during the first ten seconds after learning is sharply retarded from delays of 10 seconds to 30 seconds after learning (see Wickelgren and Berian, 1971), but this could simply be due to the presence of a long-term trace immediately after learning. However, some studies have found a temporary increase in the memory trace (reminiscence) occurring from delays of about 10 seconds to delays of about 20 seconds (Keppel and Underwood, 1967; Peterson, 1966). Reminiscence can be explained by assuming that a decaying short-term memory trace is compensated for to a greater or lesser extent by a consolidating long-term memory trace. In this case, the long-term trace is assumed to appear over the interval from 10 seconds to 30 seconds after acquisition (Wickelgren and Berian, 1971). However, reminiscence is not a very reliable phenomenon, and there is really very little psychological evidence for consolidation in normal human retention.

A second line of evidence for a consolidation phase comes from the effects of electroconvulsive shock (ECS) in animals and concussion injuries in people. Studies of the effect of electroconvulsive shock delivered to animals shortly after a learning trial indicate that the most consistent and damaging effects of this ECS occurs when the ECS is delivered within a few seconds or 10's of seconds following learning (see Weiskrantz, 1966). Occasionally, deleterious affects of ECS on memory are obtained with longer delays between learning and ECS, but this is much more variable and several investigators have concluded that it is probably due to a different sort of process.

In human beings, severe head injuries frequently cause permanent loss of memory for the last few seconds or 10's of seconds preceding the injury. This "short" retrograde amnesia, which is invariably permanent, is to be distinguished from "long" retrograde amnesia, which may extend for 10's of minutes, hours, days, weeks, or years prior to the injury and is usually reversible with time. Short retrograde amnesia may reflect inadequate time for consolidation of long-term memory. Long retrograde amnesia probably reflects a quite different process.

Unfortunately, neither the physiological nor the neurological evidence for distinguishing short retrograde amnesia and long retrograde amnesia is completely convincing. There is really no sharp temporal cutoff between short and long retrograde amnesia, suggesting the possibility that these are merely on a continuum. If this view is correct, then perhaps all short retrograde amnesia phenomena can be explained in the same manner that long retrograde amnesia will be explained in the subsequent section concerned with the storage phase.

Storage. During acquisition and consolidation, the memory trace is assumed to be protected to some extent from various degradative forces. At the end of the acquisition and consolidation phases, the memory trace enters the storage phase in which it becomes subject to these degradative forces. Existing evidence clearly indicates that the degree of degradation of the memory trace depends upon the nature of the activities the *S* engages in during the retention interval as well as the time involved. That is to say, we cannot assume a pure time decay process for either short-term or long-term memory. We must assume that subsequent activity causes storage interference. Storage interference refers to a reduction in the strength of previously established memory traces as a result of intervening activity. By contrast, retrieval interference refers to a reduction in the probability of correct recall as a result of

establishing competing memory traces during the retention interval, but not necessarily weakening previously established memory traces.

In the case of long-term memory, the degree of storage interference caused by interpolated activity is greater for interpolated activity that involves material which is similar to the previously learned material (Wickelgren, 1971).

In the case of short-term memory, however, interference increases with the amount of material learned or processed in the retention interval and the difficulty of such learning or processing (Wickelgren, 1970b). Also, interference is greater when the interpolated material is in the same modality or is of the same type as the previously learned material. However, within these *gross* limits of similarity there appears to be no further dependence of storage interference on the fine-grain similarity of interpolated material to originally learned material (Bower and Bostrom, 1968; Wickelgren, 1967). Thus, the storage interference properties of short-term and long-term memory are somewhat different, but both types of memory do show storage interference effects and cannot be described by a passive temporal decay process.

There appears to be an active trace-maintenance process (unconscious rehearsal) for short-term memory that serves to maintain the trace against the forces of decay. This trace-maintenance process operates more effectively the less time is spent on learning (as opposed to nonlearning information processing) during the retention interval. This accounts for why one obtains storage interference effects which are nevertheless independent of fine-grain similarity of the interpolated material to the previously learned material (Wickelgren, 1970b).

The short-term memory trace can be characterized by a single quantity which we might call the strength of the short-term memory trace. However, long-term memory traces appear to have two important dynamic properties: *strength* and *resistance*. The strength of the memory trace determines the subject's ability to recognize or recall material based on that memory trace. The resistance of the memory trace determines how sensitive that memory is to the subsequent forces of decay (storage interference). More resistant memory traces are less affected by the same force of decay than less resistant memory traces.

A rather simple theory appears to describe the principles of the dynamics of storage in long-term memory (Wickelgren, 1971). The theory makes four assumptions: (a) the rate of decay of strength equals the force on the trace divided by the resistance; (b) force is proportional to trace strength and to the similarity of current traces to the previously established trace; (c) resistance increases as the square root of trace age; (d) the resistance of a trace transfers completely to subsequent increments.

The meaning of the first two assumptions is relatively obvious. The third assumption indicates that a trace increases in its resistance (susceptibility to decay) the longer it has been since it has been established (learned). The fourth assumption asserts that multiple, separated, learning trials contribute increments to degree of learning that all have their resistance determined by the time since the *first* learning trial. Alternatives to the fourth assumption include assuming that resistance is determined entirely by the *final* trial of a series of learning trials or that the increment to learning contributed by each learning trial has its own resistance.

Wickelgren (1971) shows that this theory of storage in long-term memory accounts for the form and relative decay rates of a large variety of different long-term retention functions obtained for delays from 1 minute to 2 years for a variety of different subjects and a variety of different types of verbal materials learned under a variety of different conditions. In this respect, the theory provides a quantitative formulation of Jost's Second Law (in Hovland, 1951) that the rate of forgetting decreases as the retention interval increases. The close fit of the present quantitative formulation to a large variety of different retention functions over the relatively enormous span of time from 1 minute to 2 years argues rather persuasively that this quantitative formulation is not far off.

In addition to accounting for the form and rates of retention function, the greater resistance of older traces accounts qualitatively for long retrograde amnesia (Wickelgren,

1971). Such long retrograde amnesia is characterized by *S*'s losing all memory for events that have occurred over a period of minutes, hours, days, weeks, months, or years preceding some serious insult to the brain. The remarkable thing about this long retrograde amnesia is that it is in no way explainable by the strength of memory traces. That is to say, it is not the weak memories or the strong memories that one loses in long retrograde amnesia. Rather it is the *recent* traces, irrespective of strength, which are lost, with the period of time lost being apparently continuously variable over different subjects with different degrees of severity of brain injury (Russell, 1959).

The theory also incorporates similarity-dependent storage interference (discussed in the coding section) by means of the assumption that the force of decay is proportional to the similarity between currently learned material and previously learned material.

The theory accounts for the smaller rate of decay following spaced learning trials than following massed learning trials (Keppel, 1964; Wickelgren, 1971). Accounting for the beneficial effects on long-term retention of spaced learning trials is the primary justification for the fourth assumption of the theory that the resistance transfers completely to subsequent increments.

A variety of other phenomena may be simply described by the theory, but further study is required before definite conclusions can be drawn. These phenomena include the possibility of slower forgetting rates following relearning of forgotten material, judgments of the recency of different events, and the effects of arousal on retention (to be discussed in a subsequent section).

Retrieval. Of course, it must require some period of time to retrieve memory traces in recall and recognition memory tasks. However, very little is known concerning the dynamics of retrieval. If one distinguishes between retrieval time (which selects traces) and decision time (which selects a response in a recall or recognition memory task), then nothing definite is known about each of these two possibly independent components of retrieval time.

However, there have been a considerable number of studies concerned with recognition memory and recall latencies. These studies demonstrate consistent patterns of differences in memory response times, although we cannot, at present, decide how much of the effects to attribute to differences in retrieval time vs. differences in decision time.

The one well-established generalization that can be drawn from all of the studies of memory response times is that memory response time decreases with increasing difference in the memory strengths of correct and incorrect alternatives. In long-term recall tasks, increasing the strength of association between two items decreases the recall time, even for many trials after the last error (e.g., Millward, 1964). In short-term recall tasks using nonrehearsal instructions, the recent items (which have the greatest strength as measured by recall accuracy) have the shortest probe recall times (Norman, 1966). In short-term recognition memory, greater strength of correct alternatives leads to faster response times when strength is manipulated by changes in list length (Sternberg, 1966) or recency (Corballis, 1967). Furthermore, Norman and Wickelgren (1969) have shown that strength as measured by confidence judgments correlates with strength as measured by latency judgments in the obvious way: namely, high confidence correlates with short latency. Essentially nothing is known regarding response time in long-term recognition memory tasks, but presumably the same correlation between strength and response would hold.

There is apparently some relatively continuous speed-accuracy trade off in memory. In a paired-associate recall task, Murdock (1968) showed that requiring subjects to begin their vocal response within 1 second after the cue was presented resulted in lower recall accuracy than the somewhat more lenient requirements of 2- or 4-second latencies between probe presentation and the beginning of recall. However, the effects were far from disasterous and a rather similar decay curve of accuracy vs. recency was obtained.

Dynamic Capacity Deficits

It is possible to have a severe deficit in the ability to acquire and/or consolidate new long-

term memory traces while having little or no deficit in the retrieval of old long-term memory traces or the ability to acquire and retrieve new short-term memory traces, as discussed previously (Milner, 1966). Some recent evidence obtained by Warrington and Shallice (1969) may indicate that it is possible to have the reverse deficit, namely, a deficit in short-term memory with little or no deficit in the ability to acquire and consolidate new long-term memory traces, but this is by no means certain, at present. Whether children classified as retarded differ among themselves with respect to short-term memory versus long-term memory deficits remains to be seen. However, the evidence from brain-damaged patients suggests that this is a lively possibility.

Essentially nothing is known regarding whether it is possible to have a deficit in storage of long-term memory with no deficit in consolidation of long-term memory. Such a person presumably would form a memory trace as strong as a normal individual, but the rate of forgetting would be markedly increased. This is a possibility, but there is no directly-relevant evidence at the present time. Studies which purport to find differences in decay rate for normal versus a variety of handicapped individuals suffer from little or no theoretical motivation for the dependent variable (generally the probability of correct recall or recognition). Without some theory of the relation between the probabilities of correct recall and recognition and the underlying memory strengths, it is virtually meaningless to compare changes in response probability as a function of time for different individuals. This is especially true when the individuals differ in degree of learning measured at the shortest retention interval, but even individuals that are matched for retention by a probability-correct measure at some short delay cannot be meaningfully compared for rate of decay without justification of the dependent variable. The latter point requires a somewhat complex argument beyond the scope of the present paper. However, one should be extremely wary of comparing decay rates across different groups of individuals or as a function of different conditions, in the absence of any explicit mathematical theory of the memory trace and how it is used in retrieval for either recall or recognition.

Another issue in the comparison of decay rates for long-term memory across different groups of subjects is whether the shortest retention intervals used may be presumed to be mediated entirely by long-term memory without any contribution by short-term memory. Within the context of a two-trace theory of memory, it is obviously inappropriate to include immediate tests as measures of the degree of learning in long-term memory, since they may contain substantial amounts of short-term memory as well. One cannot be certain, at present, how long a time must elapse before the short-term trace is completely gone, but a delay of 1 or 2 minutes *filled with some rehearsal-preventing activity* is generally considered sufficient (Wickelgren, 1971).

Although there is no evidence on these matters, it is of some interest to note that within the context of the theory it ought to be possible to have an individual with a deficiency in the growth of trace resistance who would as a result have a faster rate of decay than a normal individual.

The reverse type of deficit ought to be possible as well, namely, an individual might have deficient consolidation of long-term memory with no difficulty in storage. Some very limited unpublished data of my own on certain human neurological subjects indicate that this type of disorder may well be possible.

Very likely the most typical long-term memory disorder is inadequate acquisition with perhaps no deficits in either consolidation or storage. A deficit in acquisition may be largely a matter of inadequate coding of the material in memory. Thus, a less intelligent subject may not encode the material as related to those previous memories to which it ought to be related. He does not embed the material in the kind of structure that will make it distinct from what it ought to be distinct from and related to what it ought to be related to. From a dynamic point of view, this will result in lowered degree of original learning, but according to the theory, very likely this would also increase the similarity of the material to other material increasing the decay rate. Thus, empirical demonstration of a disorder in acquisi-

tion, but not storage, could prove to be extremely difficult.

Although no consolidation process is assumed to be necessary in establishing a short-term memory trace, it is still possible that some individuals might have a deficit in acquisition of short-term memory, but no deficit in storage, while other subjects might have a deficit in storage, but no deficit in acquisition. In the area of short-term memory, according to the theory this might be relatively easy to assess by asking whether subjects have deficiencies in degree of learning as measured at the shortest delay or have deficits in the rate of decay of short-term memory. However, all of the previous comments regarding the difficulties in comparing rates of decay are applicable.

Motivational Control of Learning and Memory

Selective Attention. A person's goals control what gets learned via the selective attention mechanism. Thus, it is critical that a person have some reason for wanting to pay attention to material in order for him to learn anything about the material. Selective attention was previously discussed in the coding section.

Rehearsal. Rehearsal is another mechanism by which goals can influence learning and memory. Rehearsal aids both short-term and long-term retention by increasing the degree of learning of the material being rehearsed. As long as the amount of material being rehearsed is sufficiently small that no errors are introduced in the rehearsal process, time spent in rehearsal with the material absent is at least as valuable as the same amount of time spent with the material present. In addition, rehearsal aids short-term memory by periodically renewing the short-term trace, effectively preventing decay for small amounts of material that are within the "rehearsal span." Because of the effectiveness of rehearsal in maintaining verbal short-term traces, it is essential to use rehearsal-preventing tasks in order to study the decay of verbal short-term memory traces. However, this should not obscure the importance of rehearsal in ordinary short-term retention.

There has long been speculation regarding the possibility that imaging is a visual analogue of verbal rehearsal. Intuitively, imaging has usually been considered less effective in trace maintenance than rehearsal, but there was really little definite evidence on the matter. Recent findings by Conrad (1964) and others indicate that visually presented sequential material is translated into a verbal short-term trace (when possible). This suggests that visual rehearsal processes are less effective than any verbal rehearsal process for most people, but, of course, it does not rule out the possibility of some beneficial visual rehearsal process. However, Shaffer and Shiffrin (1972) have recently found that while increased exposure time improves the degree of learning for pictures, blank time for visual rehearsal following a picture has no effect on recognition memory for the picture. Their results provide rather strong evidence against the possibility of a visual analogue to verbal rehearsal. Thus, rehearsal may be a unique property of the verbal memory modality. Anyhow, rehearsal is apparently not a property of the visual-spatial memory modality. This lends some support to the notion that rehearsal is in some way a consequence of a special correspondence between auditory and articulatory speech representatives.

Rehearsal Strategy Deficits. Flavell, Beach, and Chinsky (1966) have shown that probabilities for spontaneous verbal rehearsal in a memory task increase as a function of age, accounting for at least part of the increasing memory performance as a function of age. Kingsley and Hagen (1969) found that nursery school subjects could be instructed to engage in rehearsal with consequent benefits for memory performance. Belmont and Butterfield (1971) found that retarded children were less likely to engage in rehearsal in a short-term memory task as compared to normal children. When the retarded children were instructed to follow a rehearsal strategy more like the normal children, their performance substantially improved. These results suggest that at least some of the short-term memory deficiencies of retarded children might be eliminated by a program of instruction regarding the importance of rehearsal for short-term retention.

Arousal. In addition to selective attention and rehearsal, there may also be an opportun-

ity for motivational control of learning via some arousal-mechanism. An enormous body of converging evidence now indicates that low arousal is deleterious for long-term learning and memory. Drugs which act as central nervous system depressants, such as alcohol, nitrous oxide, chlorpromazine, ether, etc., impair the establishment of long-term memory traces when administered either shortly before, during, or shortly after a learning experience in both humans (Steinberg and Summerfield, 1957; Goodwin, Othmer, Halikas, and Freemon, 1970) and animals (Johnson, 1969; Leukel, 1957). Drugs that increase arousal (central nervous system stimulants), such as caffein, amphetamine, nicotine, strychnine, picrotoxin, etc., facilitate long-term learning and memory when administered in close temporal proximity to the learning experience (see McGaugh and Dawson, 1971, for a review). Normal fluctuations in the degree of arousal evoked by a particular learning event (measured by the galvanic skin response, GSR) have been shown to correlate strongly with the amount of long-term memory established by a learning experience (Kleinsmith and Kaplan, 1963, 1964; Butter, 1970; Walker and Tarte, 1963). Finally, arousal induced by pairing the presentation of white noise with a learning experience also increases long-term learning and memory (Berlyne, Borsa, Craw, Gelman, and Mandell, 1965; Berlyne, Borsa, Hamacher, and Koenig, 1966; Uehling and Sprinkle, 1968).

Thus, even after the *S* has attended to the material he probably has the capability of determining the strength of the long-term memory trace that will be established for the attended material. One mechanism by which this may occur is the degree to which he encodes the material by making use of a rich and distinctive cognitive structure. Material which one regards as not very important may receive very little processing and not be encoded in any very detailed or distinct manner. Such memories are rapidly lost due to interference. On the other hand, material which is judged to be important may be encoded in a rich variety of ways, establishing a strong memory trace. Also, more important (arousing) material may be consciously rehearsed more than less important (less arousing) material. However, there is also the possibility that arousal affects learning and memory in a more automatic and less conscious way.

There has been some work on whether *S* can intentionally forget material after he has learned it when told to forget it. The evidence seems largely to indicate that there is relatively little ability to erase previously established memories in storage by instructional means alone.

Low Arousal (Depression). I would imagine that many handicapped children are more susceptible than the average child to low arousal and depression, irrespective of the type of handicap. This would be a natural emotional reaction to any serious handicap. In addition to the emotional causes of depression, the deaf, hearing-impaired, blind, or visually impaired handicapped children may be subject to an additional factor leading to low arousal. This additional factor derives from the fact that all sensory modalities provide input of a "nonspecific" nature to the reticular activating system which is responsible for maintaining an adequate degree of arousal. Thus, people with serious auditory or visual sensory deficits may be particularly susceptible to chronically low arousal.

For any handicapped person, except one with a serious selective attention problem, a rather high level of background (noise) stimulation may be an important aid to learning. Especially in the case of emotionally disturbed children, this high level of background noise stimulation may be quite the opposite of what one would ordinarily think to be indicated as a part of an emotional and intellectual relearning program. An emotionally disturbed individual whose arousal has been greatly depressed, either through normal fluctuations or drugs, is probably in an extremely poor condition to learn anything. Thus, while it may be more difficult to manage such a person under a state of higher arousal, it may also be essential to have at least moderately high arousal, if any significant learning is to take place.

In the case of an individual with a selective attention deficit, the problem may be that the individual has chronically high arousal, since he is so easily affected by a broad range of

stimuli. Thus, rather low levels of background noise may be indicated for such a person despite all of the previous comments regarding the importance of arousal for learning and memory.

For blind or deaf individuals, all of the background noise stimulation must be concentrated in modalities to which the individual is sensitive. Thus, high levels of visual noise may be necessary for a deaf person to maintain adequate arousal. High levels of auditory noise stimulation may be necessary for maintaining adequate arousal in a blind person. In addition, it is conceivable that air currents, odors, and tastes induced by eating during learning might be aids to maintaining arousal in children with various degrees of sensory deprivation in particular modalities.

Little is known at present concerning the relative importance of the absolute level of arousal during learning versus the degree of change in arousal contingent upon the learning event. The drug studies, of course, influence learning by way of the overall level of arousal over a considerable time surrounding the learning event. By contrast, the galvanic skin response (GSR) and white noise studies are usually concerned with a short-term *change* in the degree of arousal immediately contiguous with the learning event. Further research is needed on this point, since it is quite possible that too high a level of arousal might limit the degree of further increase in arousal that could occur immediately contiguous with the learning experience. If *change* in the degree of arousal is of significant importance for long-term learning and memory, then it may be that, beyond a certain point, increases in the absolute level of arousal are deleterious rather than beneficial.

Retrieval

The logical (nondynamic) aspects of retrieval refer to how memory traces are used in a variety of situations. The coding assumptions specify the different traces that are acquired and stored in memory, but also it is necessary to say which of these traces are used in various tasks (recall, recognition, etc.). For each of these tasks we must decide, "What is judged in retrieval?" Also, we must specify the decision rules which translate the value of these traces into responses in different types of elementary memory tasks.

Somewhat different retrieval mechanisms must be involved in recall and recognition, and it has sometimes been suggested that individuals can be handicapped in recall tasks, but not in recognition memory tasks. It is difficult to assess such disparities between recognition and recall performance without explicit understanding of the logical relationship between recall and recognition memory, but there is certainly a possibility of differential memory capacity deficits in recall vs. recognition retrieval mechanisms.

In addition to the possibility of capacity deficits in retrieval mechanisms, there is the likely possibility that retarded children and some children with learning disabilities may have retrieval strategy deficits. Optimal retrieval from one's memory in most real-life situations requires a complex sequence of elementary recall and recognition tasks, with one's own enrichment of the retrieval cues playing an important part in retrieval accuracy. Some children may have much poorer strategies in this regard than other children.

Elementary Retrieval

I assume that there are three elementary retrieval processes: recognition, recall, and recency, the three R's of retrieval. In "yes-no" recognition an individual is assumed to judge the strength of the memory trace for the item or pair of items that is presented in the recognition test. Only that strength is assumed to be judged, and a criterion decision rule used in Thurstonian scaling or signal detection theory is assumed to be applicable (Wickelgren and Norman, 1966). The criterion decision rule specifies that, if the strength of the memory trace is above some criterion, an individual decides he has encountered the test event previously. If the strength of the test event is below the criterion, he decides the opposite. The criterion is assumed to be under an individual's control and can be affected by his biases. The statistical decision theory that results from these assumptions, in conjunction with an assumed normal distribution of noise in the memory process, allows one to compute the average strengths of memory traces. These decision making assumptions for recognition

memory have both direct and indirect experimental support (Bower and Bostrom, 1968; Wickelgren, 1967, 1970a).

In multiple choice recognition memory, an individual is given two or more alternative items or pairs of items and is required to choose which was presented previously. This is assumed to be accomplished by choosing that item or pair of items that has the maximum strength of association. Evidence supporting the validity of this decision rule has been obtained by Green and Moses (1966) and Kintsch (1968), but there are some complicating factors (Wickelgren, 1968; Norman and Wickelgren, 1969).

In recall tasks where the number of alternative responses is very large (e.g., words, phrases, sentences), the most natural assumption is that the correct response will be selected, if and only if the strength of association from the cues to that response is above some (rather high) threshold.

Logically, recall is more difficult than "yes-no" recognition because one must choose among a large (sometimes very large) number of alternatives. Thus, recall is open to competition effects at the time of retrieval which "yes-no" recognition is not. In many circumstances the probability of correct recall will be extremely low, while the probability of correct recognition is extremely high. From a practical point of view, the greater difficulty of recall is extremely real, despite the fact that the underlying memory traces involved in recall and recognition memory may be of exactly the same type. Recall is just logically much more difficult than recognition, and human performance in this case directly reflects the difference in logical difficulty.

Complex Retrieval

Much of our everyday retrieval of memory traces involves a complex sequence of recognition, recall, and recency judgments. Thus, for example, in attempting to recall someone's name, we may try to go directly from a visual image of the person to his name. If that fails, we may attempt to generate alternative names, testing each one via recognition memory. A common scheme is to go through the alphabet trying to use the first letter in conjunction with various information about the individual (such as an image of him) to attempt to generate his name, testing via recognition memory. When we attempt to remember how long ago something occurred (at what point in time), we may use both a direct recency judgment and also attempt to recall time concepts directly or indirectly associated to the event in question. Thus, by the latter process we may remember that some event occurred 3 days ago, because we remember that it occurred just after some meeting, which we remember was on a particular date.

Distraction

Although one ordinarily assumes that recall is a desirable process, there are very likely substantial advantages for human happiness in being able to not recall certain unpleasant events. Sometimes this is deleterious, if one really needs to deal with a problem, but in other cases the painful events are over and done with and are best forgotten. Loss of the memory in storage can be a long slow process, especially for material that was extremely salient at the time it was learned. To keep from remembering these events and causing ourselves needless pain, people have the ability to prevent recall by way of distraction. Because of the associative nature of memory, an unpleasant event will be recalled only if the cues that are associated to the internal representatives of that event are present in consciousness. Thus, if we can avoid contact with all the cues associated with that event or selectively not attend to them, then we can prevent the recall of the unpleasant memories. Obviously, distraction can play only a very limited role in recognition memory, but it can play a very large role in preventing recall.

Repression

Freud and other psychoanalytically oriented psychologists have presented considerable clinical evidence that some emotionally disturbed individuals are capable of preventing recall of unpleasant memories, even when they are forced to attend to cues that would be sufficient in a normal individual to produce recall. There is no question that the memories are there, and they can be elicited by association, hypnosis, etc. However, the *S*, despite some apparent effort to attend to the cues and recall

the unpleasant memories, appears unable to do so under normal circumstances. This phenomenon has been termed repression, and besides the clinical evidence for it there is some limited experimental evidence as well (Glucksberg and King, 1967).

Retrieval Deficits

It has frequently been observed by memory psychologists that failure to recall some material does not necessarily imply that the memory trace for that material has been completely lost in storage. There are many reasons why an individual may not be able to retrieve some memory at a particular time, but may be able to retrieve it at another time under other circumstances. This is presumably much less true for retrieval of memory in a recognition test than in a recall test, but the exact extent to which recognition is free of retrieval interference phenomena of any kind has not yet been established.

Limiting our attention to recall, it is quite possible that some individuals have a deficit in retrieval with little or no deficit in acquisition, consolidation, or storage of memory traces. Most recall tasks, even most laboratory recall tasks, are not free-association tasks. We do not speak the first thought that comes into our mind upon being given the cue in a recall task. One usually goes through a process of enriching the cues by recall of associated contextual material and rejecting various incorrect thoughts via a recognition test, for some time, before deciding upon the correct answer. In a laboratory task this may be a matter of only a few seconds of such thinking. However, in real-life recall tasks, sometimes, the process of enriching the context by recall and rejecting incorrect associations by recognition goes on for many minutes. If an individual has certain cognitive deficits that lead him to be less adept at initiating and executing such a sequence of cognitive operations, then he will have a retrieval deficit that will affect his memory performance on recall tasks. In any event, it is certainly logically possible for an individual to have a retrieval deficit without an acquisition, consolidation, or storage deficit.

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4. COGNITION: A SURVEY

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The study of cognition in psychology is more intense now than at any previous time, and with the recognition that complex internal processing is involved in most learning and perception, a continual widening of the definition of cognitive psychology has occurred. While it is not to the point to attempt a formal definition of cognition here, a number of examples are given, and from these examples it will be clear how broad the current conception is. Currently not only are all the major academic skills, ranging from reading to mathematics and science, included under cognition, but also much that is classically considered as part of perception. In fact it has become increasingly difficult to draw any sharp line between cognition and perception.

From a theoretical standpoint there are many different approaches to cognition, but it is fair to say that none of them currently dominates the scene. As in the case of an exact definition of cognition, it is also not possible to give an exact definition or to delineate sharply the key theoretical concepts in the various approaches to cognitive theory. Without too much injustice, however, we can group the current theories into four classes, and the four main sections of this chapter are organized to represent each of the four main theoretical approaches.

In brief terms the four approaches are: behavioral, developmental, information processing, or linguistic in orientation. The behavioral approach to cognition is typically represented by stimulus-response theorists like Estes, the developmental approach by Piaget, and the information-processing approach by Newell and Simon, as well as current work in artificial intelligence. The linguistic approach has been most stimulated by Chomsky, but the large literature on semantics derives not from the linguistic tradition of Chomsky and his colleagues, but rather from that of logicians and philosophers. Some attention will be given to both of these linguistic approaches.

Without attempting anything like an adequate or complete survey, I have also tried to indicate for these approaches some of the relevant studies directly concerned with the cognitive capacities of handicapped children.

As I turn to these four theoretical approaches to cognition, it is important to emphasize that each is incomplete and unsatisfactory in any one of several ways. There are some reasons for thinking that we are perhaps on the verge of a real synthesis of theoretical ideas that have been emerging in psychology from a number of different viewpoints, but it is premature to indicate the lines of this synthesis. It is clear, however, that what once appeared as sharp conceptual differences between behavioral approaches on the one hand, and information-processing approaches on the other, has with time increasingly become less clear and less distinct. More is said about such a synthesis in the final section.

Behavioral Approach

The behavioral approach to cognition in the form of concept formation may be illustrated by the application of the simple all-or-none conditioning model. Bower (1961) and Estes (1961) showed that a simple conditioning model could give an excellent account of paired-associate learning. In paired-associate experiments, the learner is shown, for example, a nonsense syllable and is asked to learn to associate with it the response of pressing a left or right key. Given a list of, say, 20 nonsense syllables, half of them randomly assigned to the left key and half of them to the right key, the scientific problem is to give an exact account of the course of learning. The naive idea most of us have is that on each trial, with exposure to the stimulus and an indication of what is the correct response, learning will gradually occur. One traditional way of expressing this was that the connection or response strength would gradually build up from trial to trial.

The experiments reported by Bower and Estes showed that in simple paired-associate

learning the situation is somewhat different. The evidence is fairly clear that in the kind of paired-associate experiment just described the learner does not improve incrementally, but rather learns the association between a stimulus and response on an all-or-none basis. There is no improvement in the probability of his making a correct response until he fully learns the association. The theory of such experiments can be stated rather explicitly within a classical stimulus-response framework. The only important concepts are those of conditioning a response to a stimulus and sampling the stimuli on a given trial, together with the reinforcement that serves as a correction procedure when incorrect responses are made or that informs the learner that a correct response has been made.

One might accept such an exceedingly simple theory for paired-associate learning but doubt its ability to account for concept learning in children. Suppes and Ginsberg (1962, 1963) showed that this same all-or-none model gives a good approximation to concept learning where now the stimulus is replaced by the concept to be learned. In order to distinguish sharply such concept experiments from paired-associate experiments, Suppes and Ginsberg define a pure concept experiment as one in which the stimulus display changes on each trial, so that there is no opportunity to account for the learning data by a simple stimulus-association model.

In the Bower and Estes model, the two essential assumptions are these. First, until the single stimulus element is conditioned there is a constant guessing probability, p, that the learner responds correctly. Second, on each trial there is a constant probability, c, that the single stimulus element will be conditioned to the correct response. The only change in this model in order to apply it to concept learning is that the concept rather than the single stimulus element is now that to which the correct response is conditioned.

Without entering into statistical details, perhaps the best and most intuitive way to test this all-or-none model is to look at the probability of a correct response prior to the last error.

An experiment on learning the identity of sets in which the subjects were 48 children of

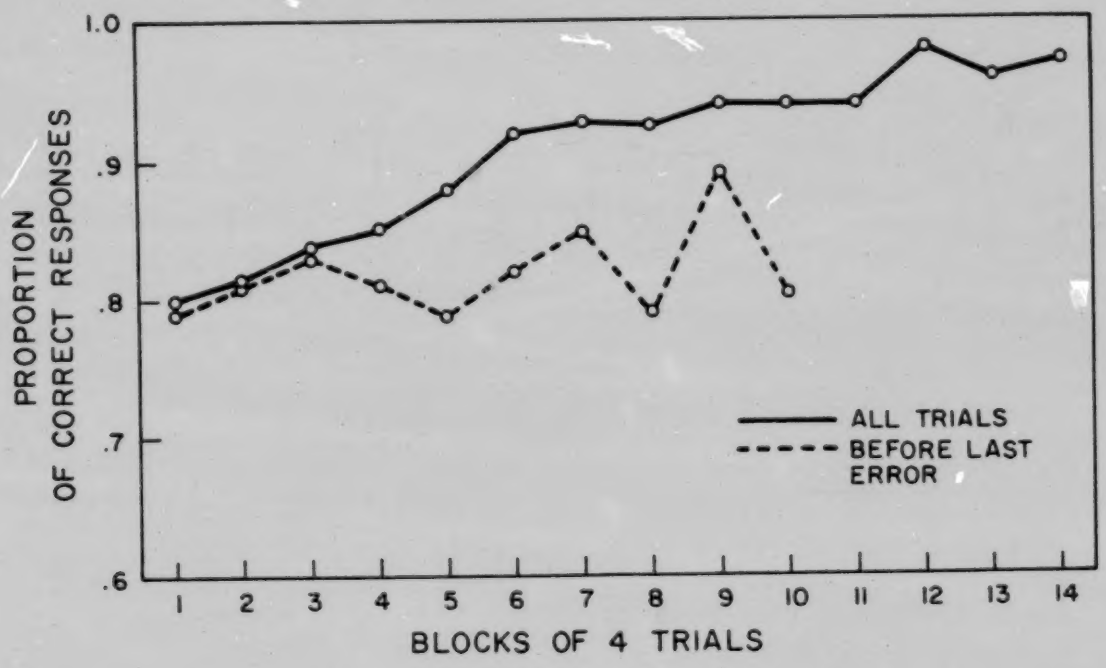

Figure 15.—Proportion of correct responses prior to last error and mean learning curve. (Identity of sets experiment.)

first-grade age is reported in Suppes and Ginsberg (1963). On each trial, the child's task was to indicate whether two sets displayed, each consisting of one, two, or three elements, were identical or not. The child was instructed to press one of two buttons when the stimulus pairs presented were "the same" and the alternative button when they were "not the same." Notice, of course, that "the same" does not mean the same from a perceptual standpoint, for permutations in the order in which the members of sets are shown do not affect the identity of the sets.

A total of 48 subjects were run through individual sessions of 56 trials on which 28 of the stimuli displayed showed identical sets and the remaining 28 showed nonidentical sets. No stimulus displayed on any trial was repeated for an individual subject. The learning data, taken from Suppes and Ginsberg (1963), are shown in figure 15. The solid curve shows the mean learning curve and the dotted curve the curve for learning prior to last error. As the all-or-none model would predict, the curve for learning prior to last error is nearly horizontal and provides approximate confirmation of the all-or-none model.

A second experiment on geometric forms was reported in detail in Stoll (1962) and was also discussed in Suppes and Ginsberg (1963). The subjects were 32 kindergarten children divided into two groups. For one group the problem was to discriminate among triangles, quadrilaterals, and pentagons, and for the other to discriminate among acute, right, and obtuse angles. From a discrimination learning standpoint, the experiment was a successive discrimination, three-response situation. For all subjects a typical case of each form was shown just above the appropriate response key and, as in the previous experiment, no single stimulus display was repeated for any

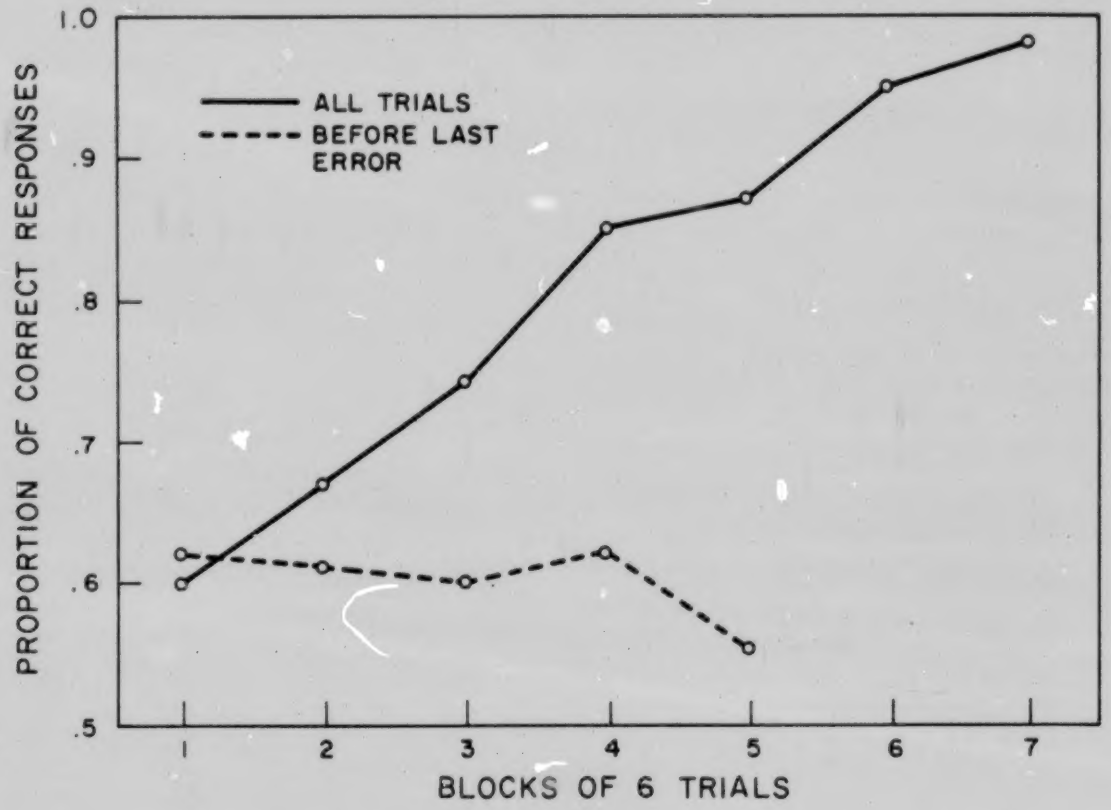

Figure 16.—Proportion of correct responses prior to last error and mean learning curve. (Quadrilateral and pentagon concepts, Stoll experiment.)

one subject. The subjects were run to a criterion of nine correct responses in any one session.

The mean learning curve and the mean learning curve prior to last error are shown in figure 16 for the quadrilateral and pentagon concepts (the learning of triangles was sufficiently fast to make the data uninteresting). The combined learning data for acute, right, and obtuse angles are shown in figure 17. In both cases there is good support in first approximation for the all-or-none conditioning model, although as Suppes and Ginsberg (1963) show, in a more detailed analysis of the data, statistically significant evidence for slight deviation from the all-or-none model can be found.

The experiments just reported indicate how an exceedingly simple behavioral model can give in first approximation an excellent account of data on concept-learning experiments with children. It should be obvious, of course, that a model as simple as the all-or-none model does not begin to give a full account of the processing that takes place in the child's learning of the concepts in question. What the model does is abstract certain features of the learning and give a good account of those features.

From a behavioral standpoint an excellent review with clear theoretical orientation of learning in retarded children is found in Estes (1970). To indicate how a more complicated behavioral model can be applied to the conceptual learning of handicapped children, it may be useful to review Estes' analysis of the Zeaman and House two-stage intentional model for discriminational learning. The Zeaman and House model is applicable to concept identification or simple concept formation and is an extension of the one-element model just described. The Zeaman and House work is almost unique in being one of the few cases in which a theoretically detailed set of assumptions has been applied to problems of concept formation

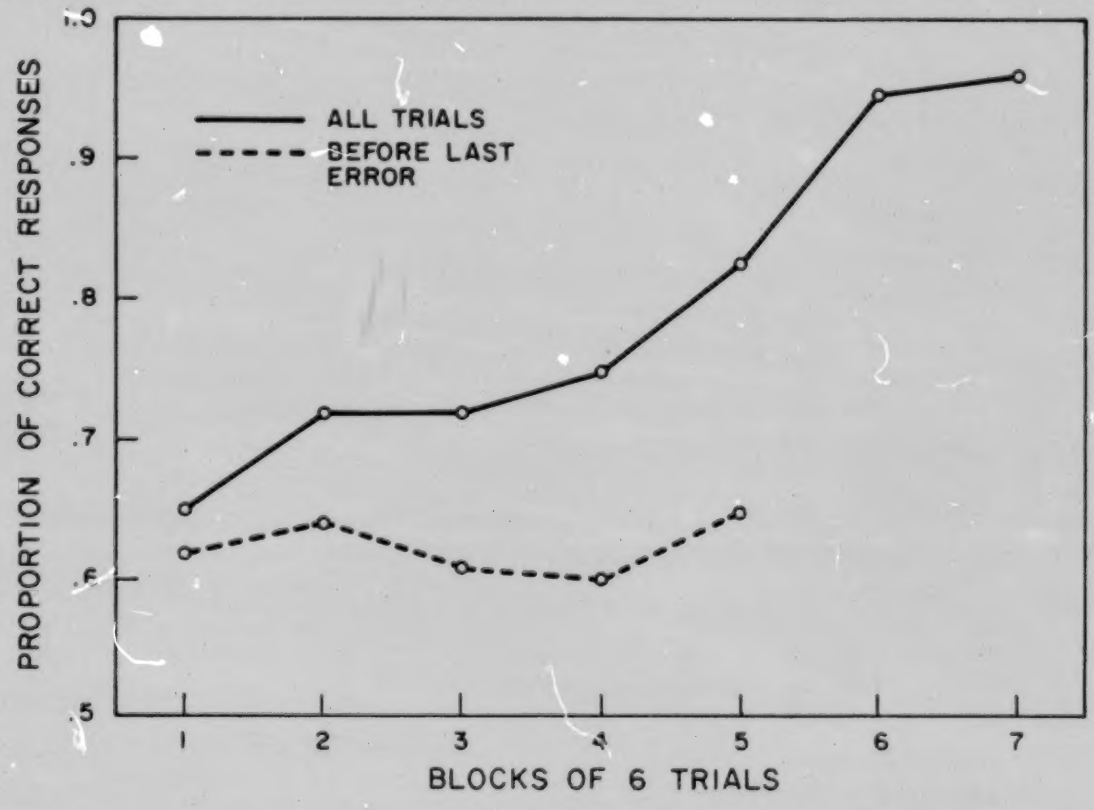

Figure 17.—Proportion of correct responses prior to last error and mean learning curve. (Acute, right, and obtuse angle concepts, Stoll experiment.)

or identification in retarded children, for example, in color-form discriminations. The two stages in their model represent an attentional process and a learning process.

What is surprising and almost paradoxical in the theory is that the main differences in learning for subjects of different mental ages are reflected in the initial attentional process, which primarily consists of learning to attend to the correct or relevant dimensions of a problem. Very small differences are reflected in the learning of the appropriate associations once the proper dimensions are attended to. In one analysis, for example, groups of children with mean mental ages of 2 years 4 months and 4 years 6 months, respectively, were compared. The curve for the higher group rose steeply from chance to nearly 100 percent correct responses over about 40 trials. The curve for the lower group differed only in that it hovered around the chance level of 50 percent correct, responding with no obvious trend for about 180 trials before beginning to rise. Then, like the curve for the higher group, the trend rose steeply to virtually 100 percent correct responses over about 40 trials.

Backward or Vincent learning curves for the data prior to last error were used in this study to detect learning trends. As Estes points out, it is hard to accept that the only differences in learning of retarded children can be identified simply as the probability of attending to the correct dimension. Since the attentional function is a probabilistic function and sums to one, this means that if the theory were pushed relentlessly, on some dimensions the performance of retarded children should be better than that of normal children, because they must have a higher probability of attending to these dimensions.

In principle individual parameters can be estimated in the model, but in practice this has not been done. In fact, I have been unable to identify any studies of concept formation or identification in retarded students, or even for groups of subjects stratified according to mental age, that actually work out models in sufficient detail to estimate in standard statistical fashion learning parameters for individual subjects. In view of the extensive work that has been devoted in mathematical psychology to the development of such models over the past two decades, it would seem especially desirable to push the detailed analysis of data by the application of such models and the identification of various phases of learning at a more abstract level in terms of the estimation of parameters. It would also be interesting to then regress the estimated parameters for individual subjects or stratified groups of subjects on variables of mental age, chronological age and other features of overall performance.

Moreover, in those experiments for which the all-or-none model fits fairly well, by assuming a beta distribution for individual differences in the conditioning parameter c, more exact and quantitative comparisons between normal and retarded children could be made by estimating such beta distributions for the two populations. It would be anticipated that in many studies the mean for the beta distribution of the retarded children would be significantly lower than that for the normal children, but the overlap in the two distributions, as well as in the scatter plots of the individual estimated parameters, would provide information to deepen our summary view on the differences and similarities of the two populations with respect to different conceptual tasks.

Using the more complex Zeaman and House model or applying the concept of individual differences to the all-or-none model still leaves us a long way from a theory adequate to account fully for the processing obviously required of the learner in mastering even a simple cognitive concept like that of identity of sets. This then is the weakness of the behavioral approach. It has not been able to develop a sufficiently complex apparatus satisfying the rigorous standards it has imposed in the analysis of data and for that part of the processing it can account for. The situation is complex and needs to be stated with some care. The theoretical issues are more subtle than we can explore in detail here, but the following points are relevant. First, it is sometimes claimed by those advocating other approaches to cognition that behavioral or stimulus-response theories cannot in principle account for complex behavior, for example, the complex processing required in language learning. These negative claims about the behavioral theory are almost

always incorrect, incorrect in the sense that the claims are asserted in dogmatic fashion. No proof is formally given that some well-defined version of stimulus-response theory cannot account in principle for complex learning. As shown in Suppes (1969), it is not difficult to give a stimulus-response theory of finite automata, and without too much trouble this account can be extended to more complex automata that are in principle adequate for language learning.

On the other hand, even though the formal criticisms are incorrect, it is certainly true that the behavioral approach is not at present able to provide an adequately detailed theory of something as complex as language learning.

Developmental Approach

A major approach to cognition has been to describe in explicit terms the sequence of concept development in children from birth to adolescence. Without question, the outstanding effort has been that of Piaget and his collaborators. The studies have ranged over most of the topics one would like to see included in a broad theory of cognition and have covered more conceptual ground than the behavioral approach just discussed. There are, for example, within the Piagetian developmental approach major studies on the following concepts: the child's understanding of spatial concepts, including both two- and three-dimensional concepts; the development of geometrical concepts; the development of the concept of distance conservation and the spatial coordinate system. Extensive and controversial studies on the concepts of conservation have also dominated much of the literature in recent years and range through the conservation of mass, weight and volume. Additional studies have been concerned with the development of number concepts and set concepts closely related to those of number concepts; for example, the notion of two sets being equivalent, that is, having the same cardinality. Still other studies have been devoted to the development of logical operations and the development of the concepts of causality and also of morality in children.

Those who want to get a deeper feeling for the Piagetian approach to cognition can look at either some of the many books of Piaget that have been translated into English or at some of the excellent readers composed of shorter articles that have appeared in recent years. The book edited by Sigel and Hooper (1968) provides an excellent survey and is recommended.

The enormous body of research studies generated by Piaget and his collaborators has given us an overview of the cognitive development of the child unequaled even approximately by any of the other approaches to cognition. The attempt has been to map out in broad terms the cognitive development along every major dimension of intellectual or perceptual skill. To a lesser extent than one might expect, this conceptual apparatus and approach to cognition has not been extensively applied to handicapped children. An example of work in this area is Woodward (1961), who considered one-to-one correspondence and equivalency of sets, as well as seriation and conservation of continuous quantity. She found that the performance of retarded adults whose chronological age was 19 and retarded children whose chronological age was 12.9 was at about a level similar to an average normal child of from 4 to 7 years.

Granted that the developmental approach of Piaget has given by far the most extensive analysis of the whole range of cognitive concepts, it is natural to ask why this approach has not been uniformly adopted by most investigators and conceded to be the soundest approach to cognition. There are, I think, three reasons for reservations about the Piagetian approach to cognition. These reasons can be given and seriously held to without at the same time denigrating the great value of the work that Piaget and his collaborators have done.

One objection to the developmental Piagetian approach to cognition is the lack of emphasis and attention given to language development. The linguistic approach discussed below emphasizes the overwhelming importance of language development for the cognitive development of a child and its advocates find far too little attention paid to the problems of language development in the Piagetian viewpoint.

The second objection has been a methodological one by many experimental psychologists to the quality of the experimental data reported by Piaget and his collaborators. The

standard objection has been that well-designed experiments have not been used as a basis for the conclusions drawn, but rather empirical methods have been based too much on anecdotal methods, or at the least, open-ended interviews in which children are verbally interrogated about their understanding of concepts and relevant cognitive tasks. This criticism is less valid than it was a decade ago, because much of the emphasis, especially on the part of American investigators following the Piaget line of development, has been on the careful design of experiments to test Piagetian concepts. There now exists a rather substantial literature of an experimentally sound character in the Piagetian tradition, and the reader will find current issues of journals like *Developmental Psychology* and the *Journal of Experimental Child Psychology* full of carefully designed experiments that clearly grow out of this tradition.

The third line of criticism of the Piagetian approach is the lack of clarity in the development of key concepts and the absence of sharply defined experimental tests of the key concepts. To illustrate the problem and to provide a comparison with the earlier discussion of all-or-none conditioning as a behavioral approach, I paraphrase and present briefly an analysis I have given elsewhere of Piaget's concept of stages (Suppes, 1972).

I select Piaget's concept of stages, because it is central to much of his work in development, and because it also has become increasingly important in developmental psycholinguistics. I hasten to add, however, that a similar analysis could be given of other key concepts. An instance of how Piaget uses the concept of stages can be gained from the following quotation, in which the analysis of three stages of multiple seriation is discussed in Inhelder and Piaget (1964, p. 270).

> We shall distinguish three stages, corresponding to the usual three levels. During stage I, there are no seriations in the strict sense. The child's constructions are intermediate between classification and seriation. . . . During stage II, there is seriation, but only according to one of the criteria, or else the child switches from one criterion to the other. . . . Finally, during stage III (starting at 7–8 years), the child reaches a multiplicative arrangement based on the twofold seriation of the set of elements.

There is in this passage, as elsewhere in the writings of Piaget, little indication that matters could be otherwise—that development could be incremental and continuous and that stages may be an artificial device with no real scientific content. No one denies that children develop in some sequential fashion as they acquire new capacities and skills. The problem is in determining whether they proceed in stages or continuously. We could of course artificially and conventionally divide any period of incremental development and label it as a particular "stage." In principle, the issue about stages versus incremental acquisition of concepts is exactly the issue faced by the behavioral approach in comparing the all-or-none conditioning model with the ordinary incremental model.

In other places Piaget does comment on the question of the actual existence of stages, but he does not address the matter in ways that seem scientifically sound. Piaget (1960, p. 121) writes as follows:

> I now come to the big problem: the problem of the very existence of stages; do there exist steps in development or is complete continuity observed? . . . when we are faced macroscopically with a certain discontinuity we never know whether there do not exist small transformations which would be continuous but which we do not manage to measure on our scale of approximation. In other words, continuity would depend fundamentally on a question of scale; for a certain scale of measurement we obtain discontinuity when with a finer scale we should get continuity. Of course this argument is quite valid, because the very manner of defining continuity and discontinuity implies that these ideas remain fundamentally relative to the scale of measurement or observation. This, then, is the alternative which confronts us: either a basic continuity or else development by steps, which would allow us to speak of stages at least to our scale of approximation.

The confusion in this passage is in the introduction of the spurious issue of the scale

of measurement. Obviously this is an issue to be discussed in a refined analysis but, as the literature on all-or-none conditioning models versus incremental models shows, a perfectly good and sound prior investigation exists at a given level of measurement, namely, the level of standard experimental studies. What Piaget does not seem to recognize is the existence of a clear alternative and the necessity of testing for the presence or absence of this alternative in providing a more correct account of the sequential development that occurs in a child.

This discussion of stages is meant to indicate the tension that exists in any fair evaluation of the work of Piaget and his collaborators. On the one hand they have without doubt contributed enormously to the current intense interest in cognition, especially in the cognitive development of children. Piaget and his collaborators have put the problem in a proper perspective by insisting on investigating not just a few skills and concepts, but the entire range that we intuitively expect and believe are part of the child's developing competence. On the other hand, both the theory and experimentation have often been loose and more suggestive than definitive. Methodological and theoretical criticisms are easy to formulate. Certainly, deeper clarification of both the experimental methodology and the theory is required before widespread applications to the critical problems of development in handicapped children are extensively pursued.

Information-Processing Approach

The information-processing approach to cognition has been deeply influenced by related developments in computer science and the widespread impact of computers themselves since the early 1950s. A good example of any early influential article in this approach to cognition is Newell, Shaw, and Simon (1958). An influential book of the early 1960s was that edited by Feigenbaum and Feldman (1963). Perhaps the most impressive recent example of this general approach to cognition is Newell and Simon's treatise (1972) on human problem solving.

In broad terms, the difference between the information-processing approach and the developmental approach of Piaget is that Piaget has primarily been concerned with the characterization of tasks and the sequence in which the child learns to solve these tasks; in contrast, the information-processing approach has been concerned with the processing apparatus necessary to handle even the most elementary forms of cognition.

As the name suggests, the information-processing approach has been much influenced by the organization of information processing in computers. There is concern that the major aspects of information processing that have been the focus of computer organization also be given attention in any conception of human processing. It is important not to be misunderstood on this point. Investigators like Newell and Simon are far too sophisticated to think that the present stage of computer developement provides anything like an adequate model of human processing. Although they do not put it in so many words, it is probably fair to say that they would regard the problems of computer organization as indicating some of the necessary but not sufficient conditions for information processing in humans.

The major feature of the information-processing approach that differs from either the behavioral or developmental approach is the emphasis on the detailed steps a person or child takes in solving a concept, and the detailed analysis of the verbal protocol that can be obtained from him in the process of mastering a problem. The information-processing approach is like the developmental approach in its emphasis on the importance of verbal reports of the subject in an experiment, but it differs from the developmental approach and is more like the behavioral approach in its emphasis on a highly detailed analysis of the structure and content of the protocol.

As is characteristic of other areas of psychology, the different approaches also tend to develop different types of tasks considered typical of cognition. The information-processing approach, especially in the work of Newell and Simon, has been concerned with cryptarithmetic, simple logical inference, and the kind of problem solving that goes into complex games like chess.

The most characteristic and important feature of the information-processing approach has been the attempt to simulate by a computer program the detailed processing in which a hu-

man subject engages in problem solving. This has proved to be both a strength and weakness of this approach to cognition. It is a strength because of the effort to capture as much as possible the explicit details of the human subject's thought processes in mastering a cognitive problem; in this ambition it goes far beyond anything that has yet been attempted in the behavioral approach. The weakness of the approach is methodological. It centers around the difficulty of evaluating whether or not the simulation, even at the level of individual subjects, provides a good match or not to the actual ongoing processing in the human subject. The very complexity of the simulation raises new methodological problems that do not arise in the same form in either the behavioral or developmental approaches to cognition.

In spite of some of the reservations one may express about the methodology, the Newell and Simon approach to cognition seems to hold excellent promise of application to the study of cognition in handicapped children. Let me give one example.

An excellent review of the relative efficiency of concept usage by retarded and nonretarded children is found in Zigler and Balla (1971); they reviewed eight major studies, which by and large equated the mental age of retarded and nonretarded subjects. A couple of the studies reported more than one experiment. The 19 experiments, whose results are summarized, included the tasks of selecting 3 pictures that illustrate a concept from a set of 7 pictures, verbalizing a concept common to the 3 pictures, associative clustering, defining all words in an experiment, sorting cards in terms of some concept, and selecting 4 pictures that illustrate a concept from a set of 7 using different types of concepts. The performance of the normal and retarded subjects was about the same in 12 of the experiments, and that of the nonretarded subjects was better in the remaining 7.

Similar results are reported in Blake and Williams (1968). Retarded, normal, and superior groups of students were compared on their attainment of concepts by deduction, induction-discovery, and induction-demonstration. When mental age was held constant, the groups did not differ in level of concept attainment. Also, for all three groups, deduction was the most effective, while the two inductive methods were about equal in effectiveness.

A recent study of Blount (1970) found no significant difference between retarded and normal subjects on a concept-usage task made up from familiar items. The task required choosing the three of five pictures that went together, as well as giving a verbal label for the exemplified concept. The only superior aspect of the nonretarded subjects' performance was in their verbal labeling of the concept. Jones (1971) studied the feasibility of educable mentally retarded children's learning simple schemata exemplified in stimulus patterns on checkerboards. While the results were positive, they were not compared with a control group of normal subjects.

Although many of these studies are well designed from an experimental standpoint and consequently report empirically significant results, what is missing almost uniformly in the studies cited, including the large group analyzed by Zigler and Balla, is a theoretical framework in which to deepen the understanding of the results. For example, we do not currently have a theoretical framework in which to pinpoint more exactly the point at which to differentiate the performance of normal and retarded subjects in a concept-attainment task. The radical difference in language competence discussed in the next section does not in itself provide an explanation of the difference in concept attainment, and we need the kind of meticulous examination of details characteristic of the Newell and Simon approach to give us a deeper theoretical insight into the differential performance of retarded and normal subjects. It would be my conjecture that the application of this theoretical approach would yield significant results beyond those obtained by the kind of primarily experimental studies without an explicit theoretical framework now characteristic of much of the concept-attainment literature mentioned above.

Recently the broad spectrum of problems attacked under the heading of artificial intelligence by computer scientists has provided also a broader based approach to cognition than the particular approach of Newell and Simon. It is not that the approach via artificial intelligence is in contradiction with that of Newell

and Simon—it is that new components with a different emphasis have been added. The work of Marvin Minsky and Seymour Papert has been especially influential in this development. They have taken this approach at a mathematical level in their book, *Perceptrons* (1969), and still more explicitly in their recent analysis of the close relation between artificial intelligence and the development of a child's intelligence. Perhaps the most characteristic feature of their recent work is the emphasis on a procedure or program on the one hand, and the process of debugging the procedure or the program on the other. The idea that learning a cognitive skill is primarily a matter of learning a procedure which itself might be broken into separate procedures, and that each of these separate procedures must go through a process of debugging similar to debugging a computer program is an important insight not previously exploited in any detail in the theory of cognition. Although the details are far from clear, it is now a widespread belief that we must be able to conceptualize the internal programs that an organism uses in solving a conceptual or perceptual problem.

Without entering into full details, I illustrate the use of programs or procedures to study cognitive behavior by some of the recent work in the Institute for Mathematical Studies in the Social Sciences at Stanford. A preliminary account of this work may be found in Suppes (1972). We take as our cognitive task the elementary algorithms of arithmetic. The objective is to give an account in terms of the kind of processing the student must learn in order to solve one of these algorithms in standard format. For purposes of the present discussion we may take as a typical example ordinary column addition, that is, the usual algorithm for finding the sum of numbers when each number is represented in a row, with one row placed vertically over another to yield the standard vertical format for addition exercises.

In considering a processing approach, basically we need to think about two things. One is the characterization of the kind of registers or memory devices available to the student, and the second is the kind of instructions, like the machine instructions for a computer, that must be learned in order to correctly process the exercise. These instructions unlike computer instructions must involve, at least in elementary and schematic form, some perceptual aspects of the problem format. For the present discussion I shall drastically simplify the perceptual situation by conceiving each exercise as being presented on a grid with at most one symbol on each square of the grid. For column addition, we number the coordinates of the grid from the upper right-hand corner, Thus, in the exercise.

$$\begin{array}{r} 26 \\ 17 \\ +34 \\ \hline \end{array}$$

the coordinates of the digit 6 are (1,1), the coordinates of 7 are (2,1), the coordinates of 4 are (3,1), the coordinates of 2 are (1,2) and so forth, with the first coordinate being the row number and the second being the column number.

In terms of registers for memory, we need in general three registers, a stimulus-support register [SS] that holds an encoded representation of a printed symbol to which the student is perceptually attending at a given moment. For the present example the alphabet of such symbols consists of the ordinary 10 digits and the underlined symbol used to terminate the column. As new symbols are attended to, previously stored symbols in this stimulus-support register must be transferred to a nonstimulus-support register [NSS]. It is also convenient to use an operations register [OP] that acts as a short-term store, both for encodings of external stimuli and for results of calculations carried out on the contents of other registers.

The set of instructions needed for column addition are then the following 10, which are formulated in terms of the use made of the three registers.

Attend (a, b):	Direct attention to grid position (a, b).
($\pm$a, $\pm$b):	Shift attention on the grid by ($\pm$a, $\pm$b).
Readin [SS]:	Read into the stimulus-supported register the physical symbol in the grid position addressed by Attend.
Lookup [R1] + [R2]:	Look up table of basic addition facts for adding contents of

register [R1] and [R2] and store the result in [R1].

Copy [R1] in [R2]: Copy the content of register [R1] in register [R2].

Deleteright [R]: Delete the rightmost symbol of register [R].

Jump L: Jump to line labeled L.

Jump (val) R, L: Jump to line labeled L if content of register [R] is val.

Outright [R]: Write (output) the rightmost symbol of register [R] at grid position addressed by Attend.

End: Terminate processing of current exercise.

Exit: Terminate subroutine processing and return to next line of main program.

A perusal of these instructions shows quickly enough that only the *lookup* instruction does not have an elementary character. In terms of these instructions we can then write subroutines or programs for solving exercises in column addition, and the manner in which we write these programs is similar to the way in which programs are written for a computer in machine or assembly language. Details are omitted, because even in the case of column addition the program written in terms of these instructions requires more than 20 lines.

The particular example chosen for discussion is simple and in certain ways rather special, but it is meant only to illustrate the approach to cognition through procedures or programs. It can be anticipated that this kind of approach will be extensively used in the decade to come, and in all likelihood a wide variety of cognitive tasks will be analyzed in terms of programs or subroutines of elementary processing instructions.

In many ways it seems especially promising to use this kind of approach for the meticulous and detailed analysis of the tasks we want handicapped children to master as part of their education. The application of these ideas to the learning or performance of handicapped children has not yet taken place, but it is a feasible and practical application for research in the years ahead, with considerable significance for practical problems of instruction.

Linguistic Approach

An excellent expression of the linguistic approach to cognition is found in Chomsky (1972). At the outset, an important difference to be noted about the linguistic approach in contrast to the three other approaches discussed already is that the linguistic approach does not in principle propose to be a general theory of cognition, but rather it concentrates on that significant part of cognition that is language dependent or consists of language skills themselves. Linguists like Chomsky consider the phenomenon of language the most important single phenomenon of cognitive psychology and, consequently, believe that a large place should be occupied by the linguistic approach to cognition, even if it is not meant to encompass all cognitive phenomena.

Linguists and psycholinguists with a strong linguistic orientation have been insistent that none of the other approaches to cognition provides anything like an adequate detailed theory of language development or language performance in either children or adults. Indeed, it is customary for linguists like Chomsky to insist that even their own theories offer only the barest beginning of an adequate approach to the analysis of language. Long ago, Aristotle defined man as a *rational* animal, but much is to be said for the viewpoint that man should rather be defined as a *talking* animal. The linguistic approach to cognition insists upon the central place of language in the cognitive behavior of man and rightly denies the adequacy of any theory of cognition that cannot account for major aspects of language behavior.

The linguistic viewpoint has emphasized understanding the complex and sometimes bewildering grammar of spoken language. There is, however, another aspect of language with a long tradition of analysis, which is equally important from a cognitive standpoint. I have in mind the theory of meaning and reference, or what is usually termed the *semantics* of a language. This semantics tradition derives more from philosophy and logic than from linguis-

tics. The current approaches run back in a continuous line to the magnificent work of Gottlob Frege in the 19th century. (A good introduction to Frege's work may be found in the volume edited by Geach and Black, 1966.) The emphasis in this century has derived from the pioneering work of Alfred Tarski, beginning with his classic monograph on the concept of truth in formalized languages (1935). In the last decade, important semantic ideas of Tarski, including above all the important concept of a semantic model of a language, have been applied to natural languages, especially by Tarski's former student, Richard Montague (1970), and also in recent work of my own (Suppes, 1971).

The purpose of these theories that derive from the work of Frege and Tarski is to give a detailed and explicit theory of the meaning of utterances in ordinary language. Just as in the case of the grammatical analysis derived from the work of Chomsky and others, so in the case of these semantical efforts, it would certainly be incorrect to claim at this time that they have been entirely successful. However, a solid beginning has been made, and, perhaps more importantly, it is now clear how the extensive conceptual developments that have arisen from the earlier work of Tarski, and that have been exceedingly fruitful in the analysis of formal languages, can also be applied to the semantics of natural language.

In principle, we should like to be able to give a detailed account of the grammar and semantics of spoken speech, and especially to trace the development of both grammar and semantics in the speech of young children beginning at an age earlier than 2 years. We are yet far from being able to achieve these objectives and from having an understanding of the mechanisms used by the child in the rapid development of his verbal abilities between the ages of 2 and 5 years.

I want to conclude this section by saying something more about the theoretical problems of developing a completely adequate and detailed theory. Before doing so, however, it will be useful to examine some of the work done in studying the language development of handicapped children. In the case of deaf or retarded children the problem of language development seems to be the most serious cognitive problem faced in training and educating these children and in understanding how explicit and carefully designed approaches to their instruction can result in maximum benefit to their cognitive development.

In presenting these examples of studies of language development in handicapped children, I have not attempted to provide anything like a systematic survey of the literature. Rather, I have selected certain studies that present results of interest to the theoretical issues characteristic of linguistic approaches to cognition. The analysis is organized around three subheadings: linguistic development of retarded children; the role of language in concept formation of deaf children; and, finally, the use of regression models in the analysis of language comprehension by deaf children. The emphasis on deaf children is partly fortuitous, due to the Institute's own concern with the teaching of deaf children over the past 3 years and the fact that my own research on handicapped children has been entirely concerned with deaf children.

Linguistic Development of Retarded Children. A major study by Lenneberg, Nichols, and Rosenberger (1964) examined over a period of 3 years the language development of Mongoloid children ranging in age from 3 to 22 years. The IQ's of the children ranged from the 20's to the 70's. Their major findings were: IQ does not predict the stage of language development but chronological age does; a significant relation exists between motor development and the onset of language; although the rate is much slower, language development in Mongoloid children is similar to that in normal children; some Mongoloid children are able to process syntactically complex sentences. These authors used their results to defend the general proposition that language development is not closely related to intellectual ability, but rather it is more closely related to general biological processes of maturation. As with most general hypotheses of this kind, the data are not presented in a fashion that permits a sharp statistical evaluation or quantitative assessment of the degree to which the hypothesis is actually supported.

A number of highly specific linguistic studies of the language of retarded children are to

be found in the literature. Lovell and Bradbury (1967) studied 160 children of ages 8 to 15, inclusive. Their three hypotheses were: (i) the ability of these children to inflect, derive, and analyze compound words improves little between 8 and 15 years of age and is generally below that of normal first graders; (ii) there is a significant relationship between reading level and the ability to inflect lexicon words; (iii) there is a significant relationship between IQ and the ability to inflect nonsense words, but little relationship between reading attainment and the inflection of such words. The data confirmed all three hypotheses.

Graham and Graham (1971) studied the syntactic characteristics of the speech of nine retarded children with chronological ages ranging from 10 to 18 years and mental ages ranging from 3 years 6 months to 10 years. Their data supported the hypothesis that non-Mongoloid retardates develop language at a different rate, but in approximately the same way as normal children.

Semmel, Barritt, Bennett, and Perfetti (1968) undertook a grammatical analysis of word associations of educable mentally retarded and normal children. In studies of the language development of normal children it has been found that as they get older they tend to increasingly give associations to stimuli falling within the same grammatical form class as the stimulus. These investigators found the highest level of such form-class responses in the older normal children and the lowest incidence of such responses in the institutionalized retardates.

Cartwright (1968) studied the written language abilities of educable mentally retarded in comparison with normal children. His subjects were 80 12- through 15-year-old educable mentally retarded and 160 8- through 15-year-old normal children. Comparisons were made on the following language measures: composition length, sentence length, type-token ratio, percentage of usage of different parts of speech, grammar and spelling. The normal children of the same age had significantly higher scores on all these measures. Younger normal children, ages 8 through 11, obtained significantly higher scores than the educable mentally retarded group on three of the measures; namely, type-token ratio, grammar, and spelling. The absence of difference in sentence length is significant, considering the extent to which mean utterance length is currently used as a measure of language development by a number of psycholinguists.

One of the more extensive studies of the spoken vocabulary of retarded children has been made by Beier, Starkweather, and Lambert (1969). They interviewed 30 retarded children and recorded 2,700 words from each. The approximately 80,000 words of output were analyzed and compared with the output of normal children. While they found differences in the word lists, they also found a large number of similarities in performance of the retarded and normal groups. They interpreted their overall findings as supporting the assumption that mentally retarded children suffer from a conceptual and organizational deficit in their language usage.

These various studies show that even if the sequence of language development is similar in normal and retarded children, most cognitive functions of language are less developed in retarded children. However, it is not yet clear whether the deficit is most pronounced in the primarily cognitive aspects of language. Much better and more detailed data on the impact of training would also be most desirable; for example, the rate of acquisition of new words, the rate of improvement in spoken and written grammar.

Language and Concept Formation in Deaf Children. Excellent reviews of the literature on concept formation in deaf children have been provided by Furth (1964, 1966, 1971). In the most recent of these reviews (Furth, 1971), 39 studies are listed and summarized. The fundamental issue raised by Furth and many of the investigators whose experiments he summarized is the question of whether deaf children show a deficit in concept formation once verbal aspects of the task are removed. Put another way, in experiments that require no verbal comprehension are there significant differences in performance between deaf and normal children? Even more than in the case of concept formation or identification by retarded children, Furth has presented persuasive evidence from a number of experiments that there are often not significant differences. As he ad-

mits, the situation is not simple, and contrary evidence can be cited. The important issue, however, is the role of language in concept formation. Here, it seems to me, Furth does not really make a strong theoretical point, because his analysis is concerned entirely with command of a standard natural language. As he points out, in letter recognition tasks and others, the processes deaf children use are not clear. Process-oriented approaches to cognitive skills seem to argue strongly that some sort of language is being used internally, even if the language is not that of the society in which the children live.

Apart from the issue of the necessity of an internal processing language, two other remarks may be made about Furth's position. The first is that it would be interesting to see what the performance of deaf children who understand sign language would be if sign language were used to provide equivalent verbal instructions, or in the case of responses, to provide a medium for response by the child. There are of course some difficult problems of methodology. If comparison with normal children is desired, as in most cases it is, then comparability of the two media of communication is needed to judge whether a communication deficit exists. The methodological problem is rather similar to the study of concept formation in blind children when concepts are transferred from the visual to some other sensory modality.

The second remark concerns Furth's discussion of logical reasoning and the claim from some of his own experiments that deaf children exhibit capacities that show only small deficits at most. The point is that the experiments on logical reasoning are all extremely elementary. More complex kinds of inference, even of the kind that can be given young normal children (ages 6 and 7 years, for example), are difficult to test outside a verbal context. For example, in Suppes (1965), data on the intuitive inference capacities of young children are cited for the classical forms of inference running from modus ponendo ponens to quantificational logic using universal and existential quantifiers and two-place predicates. The experimental items are all verbal in form, and it would not be possible to give an exact parallel in nonverbal form.

When we turn to still more complex material requiring logical inference, the situation is even more completely and more throughly imbedded in a verbal context. I mention, for example, recent studies of the kinds of mathematical proofs given by college students in introductory logic courses (Kane, 1972; Moloney, 1972; Goldberg & Suppes, 1972). Here again, more sophisticated forms of reasoning can scarcely be investigated in a nonverbal context.

Language Comprehension in Deaf Children. The most salient missing aspect of the analyses of the language of either deaf or retarded children is the absence of serious attention to the semantics of their language and the identification of defects in semantics, either in terms of comprehension or production. The problems of identifying difficulties of comprehension may be approached at many different levels of detail.

An example of a medium level of detail, without a really satisfactory underlying theory, may be given from some research conducted in the institute on the written language comprehension of deaf students. This example applies the kind of regression methods we have used extensively for the analysis of relative difficulty of exercises in elementary mathematics (Suppes, Hyman, & Jerman, 1967; Suppes, Jerman, & Brian, 1968; Suppes & Morningstar, 1972). The regression models considered were developed and tested by Mrs. Jamesine Friend, who was coordinator of the project in computer-assisted instruction for deaf students in the institute from 1968 to 1971. This example deals with the analysis of difficulties deaf students encounter in reading and following written directions. The directions occur at the beginning of the computer-assisted instruction course "Language Arts for the Deaf," which was delivered to deaf students in residential schools and also to deaf students in day classes using teletype terminals connected by telephone lines to the institute's computer at Stanford. Some examples of the directions are the following. I show in capital letters the question and the example to which the question must be applied.

Example 1 (from Directions Lesson 1):
// WHICH IS THE FIRST WORD?
SOME DOGS ARE FRIENDLY.

Example 2 (from Directions Lesson 2):
// WHICH WORD COMES AFTER "VERY"?
MY TYPEWRITER IS VERY BIG AND HEAVY.

Example 3 (from Directions Lesson 9):
// WHICH LETTER COMES BEFORE "E"?
SILVER

Example 4 (from Directions Lesson 16):
// TYPE THE LAST TWO LETTERS.
MILLION

Example 5 (from Directions Lesson 25):
// TYPE THE NUMBER BELOW 4.
2 7
6 4
8 3

A number of structural features in these exercises affect their difficulty. In this kind of analysis we identify the structural features independent of any response data from the students, so that typical structural features are syntax, number of words, number of characters, and so forth. Variables of this kind have been used as structural features to predict the relative difficulty of arithmetic word problems (Jerman, 1971; Loftus, & Suppes, 1972; Suppes, Loftus, & Jerman, 1969). Mrs. Friend identified 14 such variables in the context of the language arts exercises on following directions. The variables she tested are the following.

Variable X_1: 0 if the direction is imperative.
1 if interrogative.

Variable X_2: 0 if the direction is a simple sentence or a transform of a simple sentence.
1 if compound.

Variable X_3: Number of key words in direction. ("Key words" distinguish one direction from another within the same lesson. In Example 1 above, there is only one key word, "FIRST," whereas in Example 5, there are two key words, "LAST" and "TWO.")

Variable X_4: 0 if the position cue is named (as in WHICH LETTER COMES BEFORE "E"?).
1 if the position cue is described (as in WHICH LETTER COMES BEFORE THE LAST LETTER?).

Variable X_5: Number of words in the instruction.

Variable X_6: 0 if direction does not contain "above," "below," "under," "before" or "after."
1 if it contains "above," "below" or "under."
2 if it contains "before" or "after."

Variable X_7: Lesson number.

Variable X_8: Ordinal position of the exercise within the lesson.

Variable X_9: 0 if preceding exercise involved the same task.
1 if otherwise.

Variable X_{10}: Number of elements (words, letters, numbers) in the stimulus display.

Variable X_{11}: 0 if there are no critical distractors, i.e., distractors that would be correct responses if the direction from the preceding exercise were used.
1 if otherwise.

Variable X_{12}: Length of correct response (in characters).

Variable X_{13}: Number of distractors preceding the correct response.

Variable X_{14}: Number of characters in the stimulus display (spaces not included).

These 14 variables were applied to predict the mean probability of a correct response to each of 125 exercises in lesson pretests for a sample of some 300 students. To be explicit, the regression equation is first transformed, because in an ordinary additive regression probability is not necessarily preserved, and we can

TABLE 1.—Step-Wise Linear Regression for 125 Exercises on Following Directions

Step number	Variable number	Multiple		Increase in R^2	F value for del.	Last regression coefficients
		R	R^2			
1	6	0.37960	0.14410	0.14410	20.7108	—0.01019
2	13	0.56850	0.32319	0.17910	32.2826	—0.01903
3	7	0.59690	0.35629	0.03310	6.2309	—0.04448
4	9	0.61200	0.37454	0.01825	3.4883	0.00387
5	10	0.61880	0.38291	0.00837	1.6261	—0.02949
6	14	0.62590	0.39175	0.00884	1.7131	0.00180
7	2	0.62880	0.39539	0.00364	0.6907	0.09375
8	8	0.65500	0.42903	0.03364	6.8437	0.00531
9	4	0.66430	0.44129	0.01227	2.5144	0.03370
10	15	0.66930	0.44796	0.00667	1.3822	0.00102
11	5	0.67070	0.44984	0.00188	0.3970	—0.01215
12	11	0.67130	0.45064	0.00081	0.1502	—0.00182
13	12	0.67160	0.45105	0.00040	0.0735	—0.00588
14	3	0.67190	0.45145	0.00040	0.0820	0.00952

get predictions of negative probabilities or probabilities greater than one. We have therefore customarily used the transformation

$$z_i = \frac{\log 1 - p_i}{p_i}.$$

The regression equation then assumes the following form in terms of the dependent variable z_i

$$z_i = \Sigma\, a_i x_i + a_0.$$

The results of the stepwise linear regression are shown in table 1. Nine of the variables account for 44 percent of the variance and the remaining five contribute little. (The square of the multiple correlation (R^2) is a measure of the percentage of variance accounted for by the model.) The most powerful variable is X_6, which deals with the inclusion or exclusion of certain prepositions. The relative difficulty deaf students have with prepositions is well known and familiar in the literature. The second most important variable is X_{13}, which deals with the number of distractors preceding the correct response. This variable corresponds closely to a serial position variable for the correct response. The other variables entering during the first nine steps of the regression, namely, variable X_7, X_9, X_{10}, X_{14}, X_2, X_8, and X_4, each contribute something, but do not make the dramatic contribution of variables X_6 and X_{13}.

Regression models of the kind just described are by no means a final answer to the theoretical problems of language production or recognition on the part of deaf students. They do provide a good first entry into the detailed study of comprehension. From the standpoint of constructing curriculum they can be especially useful in providing a practical technique for creating items of a given desired level of difficulty, for new items—questions or exercises—can be written such that they have specified values of the structural variables, and thus a predicted probability correct for a given reference population of students.

I return to theoretical remarks about the linguistic approach to cognition in the final section on the problem of synthesis.

Can There Be a Synthesis?

The four approaches to cognition sketched in this article would seem on the surface to be so diverse, both in their methodology and concepts, as well as in their range of actual application, as to offer little hope for a synthesis and the development of a unified theory of cognition in the immediate future. It would be a mistake to be too sanguine about the development of such a theory, but I do think there has been an increasing tendency in the past few years for the four approaches to come together.

This seems to be occurring under two headings. One is the emphasis in all approaches on the problems of language learning and behavior. An increasingly central interest in language is not the exclusive option of the linguistic approach, but is becoming dominant

among behaviorists and Piagetians alike. The second unifying theme is the emphasis on process. Behaviorists have from the start been interested in the mechanisms of learning and the study of how these mechanisms work in the acquisition of cognitive concepts. The developmental approach of Piaget and others has not been overly successful in spelling out specific mechanisms of concept acquisition, but on the other hand the many structures they have attempted to describe that are essential to the development of a child's cognitive powers have naturally suggested the nature of some of the mechanisms involved. The information-processing approach is of course primarily process-oriented, and these remarks about process lead me to my final remarks about reaching for a detailed understanding of the grammar and semantics of children's speech.

Methods that provide detailed descriptions of the grammatical and semantic structure of children's speech are needed and will continue to be developed. What will have an even more powerful effect in deepening our grasp of cognition is the development of procedural grammars and semantics that yield not only a proper analysis of the structure of children's speech, but that also provide in first approximation the necessary mechanisms for generating the speech, both in its grammatical and semantical features. There is currently throughout the world an increasingly intensive focus on these matters on the part not only of psychologists interested in cognition and psycholinguistics, but also on the part of computer scientists concerned mainly with artificial intelligence, linguists concerned mainly with language, and philosophers and logicians concerned mainly with the theory of meaning and reference. It is perhaps not too optimistic to anticipate considerable scientific progress in the next decade. At the same time we can also hope that aspects of that progress will enable us to understand better the cognitive development of handicapped children and the ways in which we may facilitate their development, as well as to map the limitations of what we may hope to do in the best of possible circumstances.

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5. LANGUAGE DEVELOPMENT

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What Is Meant by Knowing a Language?

There are many practical situations in which one may be in doubt whether a subject actually knows English or whether he is just doing something that superficially resembles speaking without any real knowledge of English. The classical example of the latter is the parrot. Recently, two young female chimpanzees are said to have acquired skills that are, in the eyes of their trainers, like knowing English, though many observers continue to be skeptical (Ploog and Melnechuk, 1971). Even among humans it is not always clear whether an individual in fact *knows* a natural language. Clinicians are often faced with patients whose language behavior is so deviant from the norm that serious doubts may be raised about their language capacities. Such borderline cases are valuable for our understanding of the nature of language. It is clear why this should be so; just as it is difficult for us to appreciate the vital nature of the atmosphere until we are deprived of it, it is difficult for us to see just what we do when we understand and speak a language until we are faced with malfunctioning of the mechanisms involved. Language is so intimately interwoven with our cognitive life that we normally find it hard to imagine what "language-free cognition" would be like. (Yet such conditions exist among the congenitally deaf before formal instruction in language or sign communication has begun; Furth, 1966.) Let us start with some operational tests for language knowledge.

Suppose we train a subject (throughout this first section, *subject* stands for normal child, neurological patient, or experimental animal alike) to hand us an object placed before him upon being given a certain signal. For instance, when the light goes on he finds in front of him either a box, an apple, a bottle, etc.; he learns that he is expected to pick it up and give it to the experimenter. After he has learned this game we start building up a vocabulary. Each object will have its own signal, say the spoken English word that corresponds to it, or some graphic representation, or some tactual pattern—the sense-modality is immaterial. As soon as the subject performs correctly on some 10 words, we begin to train him (by whatever means we can think of) to execute commands of the following type: when the light goes on, the subject will always find two objects in front of him, selected from among those whose "names" he seemed to know. However, now he is no longer to hand the experimenter automatically whatever is in front of him, but he must wait for special instructions. For instance, one instruction might be expressed by the word (graphic symbol, etc.) "and;" another by the word "or;" yet another by the phrase "the larger," etc. The first instruction is followed correctly only if the subject hands both objects; the second only if he hands one of the two objects; the third only if he picks up the larger; and so on. It is clear that each instruction is, in fact, a command of how to relate the two objects before him to one another. "Relate object 0_1 to object 0_2 'and-wise' ('or-wise,' 'comparatively-bigger-wise,' etc.) before handing them to the experimenter"—is what the instructor is essentially saying to the subject.

What our next step in training ought to be is clear enough; since we only chose objects whose "name" the subject had learned previously, we should now leave all of the objects he knows permanently in front of him, but instruct him verbally which two objects are to be related in the specified way in the handing-game. Natural languages abound with relational instructions of this sort. Virtually every utterance in English has (or implies) just about as many relational instructions as "names" of things. Therefore, if we want to test for language knowledge or the capacity for language knowledge, it is only reasonable to investigate the set of relations as carefully as the vocabulary. If our subject can name 10

objects, we should find out whether he can as easily learn to follow, say, 10 relational instructions. Prepositions lend themselves very nicely to this. In general, we would now be saying to the subject "Relate word w_1 to word w_2 in manner phi, or in symbols

(1) $$(w_1, w_2)\phi$$

where phi is a potentially open set of relations, and w_1 and w_2 are elements from a potentially open set of object-words.

So far, the task used in order to enable our subject to give evidence of his knowledge was completely fixed. It was a standing order to hand objects to the experimenter. Because of this standardization, it did not have to enter into the language of instruction. It was no different in this respect from a lever-pressing "instruction" to a rat in a Skinner-box, which is also transmitted to the rat without the use of English. The meaning of our formula (1) was pegged to this standard instruction. But natural languages have no such fixed reference; one may change imperatives as freely as one changes shirts. It is a variable in its own right. Instead of the imperative "hand to experimenter," I might choose to train my subject to "look at," "point to," "avoid by escaping," "place," etc., and relate these imperatives to phrases of the type (1). Formula (1) is thus revealed as incomplete; we simply did not bother to write down the imperative (or, more generally, the context of the formula) because, in the artificial situation that we created, it was constant. Now that we are about to add this sort of more variable instruction to our subject, we had better create a symbol that indicates the context for formula (1). Since we started out with an imperative "give," let us say that the context of the formula shall be symbolized by gamma, thus:

(2) $$[(w_1, w_2)\phi\ w_3]\gamma$$

where gamma stands for any instruction on how to relate (1) to something else.[1] The Greek letter as in the earlier formula, stands for a general set of relations; the imperative "give" is one such. It relates the words both to the listener and/or to the speaker in specific and complicated ways. Among the possible relational instructions are those that relate a statement to either people and their actions or to other statements. An example of the latter might be "The bottle or the apple is in the bigger box."

Notice that we are not particularly concerned here with just how the information is to be encoded, what physical form the signals to the subject must have, or how they are to be arranged sequentially. It is quite immaterial for this discussion whether the vehicle of communication is standardized English. The essential aspect of language that we wish to bring out is this: we implied that there is a class of words that are the *names of objects* (table, chair, box); this was our class W. Further, that the constituents of this class are constantly being related to one another during discourse, and that each such relation has its own name. Thus the names of relations (Greek letters) seemed to constitute a second class of words—one that apparently was to be treated as distinct from the class W; let us call this second class *function words.* (Synonyms for the two classes are lexical items and operators; content words and functors.)

We would now like to show that this dichotomous classification is actually quite unsatisfactory, as it implies a formal distinction that is impossible to make precise when it comes to natural languages. This difficulty, which we shall illustrate presently, is undoubtedly due to an important feature of language. Proper appreciation of the nature of language depends upon the countenancing of this difficulty.

"Names of objects" is merely a convenient fiction, upheld at the risk of the erroneous impression of the existence of fixed, absolute (i.e., nonrelative) semantic items in the language system. In fact, words are themselves relations. This situation is most obvious in the

[1] In natural languages the relations (Greek letters) are either given by "little words" or by affixes or by word order or by a combination of any one of these with the semantic relations expressed in the sequence of words as a whole. For instance: "fish like food" is fairly automatically construed as analogous to "monkeys like trees," but it could also be either of two imperatives *to fish*—alternatives that no one would choose because it would result in meaningless sentences. The same three words might also be construed as any one of the following triple compounds: fish-like food, fish like-food (which has no meaning in English) or as a phrase analogues to "food like fish" (i.e., food such as fish) which again is unlikely because of its lack of meaning.

case of kinship terms (aunt, cousin, mother, etc.). It is also obvious in most of those cases where the W-constituent is an adjective (tall and dark; pretty or witty, etc.); these words can only be understood with respect to a reference base (tall with respect to grass, buildings, people). It is true even of such words as table, box, chair, etc. This may be seen from the fact that one and the same physical object may easily be labeled with any one of these three *names*, depending on the use that is being made of it. In other words, names of objects can only be said to be correct relative to given circumstances.

The extraordinary conclusion one must draw from this discussion is that virtually every aspect of language is *relational*. It is true of content words, of function words, and, of course it is *a fortiori* true of the combination of words. Any kind of concatenation of words in any language and at any stage of language development implies relations between the concatenated words. This is best illustrated by those concatenations that do not include a function word at all. In mature English they occur, for instance, in compounded nouns (cf. lady-driver, screw-driver, lady-killer, lady-bug, or lady-like). Notice that each compound may either be expanded into a phrase of independent but interrelated words, as is done for example, in dictionary definitions, or be replaced by a single word contraction or synonym (e.g., lady-killer; expansion: someone who attempts to impress or overwhelm ladies; contraction: dandy). It is in compounds that we see most clearly how words come about; they are shorthand for something that can readily be "explained" in terms of a phrase or sentence—a whole composition of relations and interrelations. Compounds are half way between an explicit relational structure (phrase or sentence) and a single symbol (word or morph) that summarizes or stands for this more complex composition. Thus a universal property of languages is that words or morphs may be analyzed as complex relations; further, that there are substitution operations (transformations) by which any relational composition may be replaced by a single morph and, vice versa, any single morph may be replaced by an explicit relational composition. It is a reversible mapping:

(3) relational composition $\longleftrightarrow$ single morph

It will be useful to emphasize here the affinity in this respect between the structure of language and the structure of ordinary arithmetic. Everything we have said about a language such as English might as readily have been said about the much more specialized language of numbers. A short elaboration of this point might make it easier to illustrate just what is meant by phrases such as "learning or knowing a language."

In arithmetic, numbers may be seen as the content words; the symbols that instruct us what to do with numbers (such as addition or multiplication) may be seen to correspond to the function words (and, times, etc.). Arithmetic phrases are "one and two," "one times two," or, in more general form, they may be regarded as a pair of numbers n_1, n_2, together with an instruction of how to relate these. Formally:

(4) $(n_1, n_2)\phi$

Arithmetical sentences (one and two is three) may then be represented:

(5)
$$(1, 2) \xrightarrow{+} 3$$
$$(1, 2) \xrightarrow{\sim} 1$$
$$(1, 2) \xrightarrow{'} 2$$

Every content word in this language (i.e., number) stands for a host of inherent possible relational compositions (e.g., 3 is the same as 1+1+1, 256–253, etc.), and every composition may be replaced by a content word. In arithmetic, we call this sort of relating *computing*, and we know that this means to operate on something, to engage in certain specific activities. Notice that numbers themselves are constructed by us; that is, they are the result of operations that we have performed. We do not pick them up readymade, so to speak; nor does one recognize specific numbers (larger than seven) in nature. The operations from which a number is derived may be iterated without limits, and thus an infinity of numbers is generated. And just as there is no end to numbers that are constructable by the iteration of a small number of operations, so there is no end to the words that we may construct by the iterated operations available through language. (Children, for example, in their earliest language stage often do not feel constrained

by lack of lexical knowledge; they readily make up a word if society hasn't yet provided them with one, and it is not at all uncommon to be given, by the word-making child, an explicit definition of his neologism.) The infinity of "namables" is, however, not so much reflected by the expandability of the lexicon, as by the mapping operation of (3). Every word has a given semantic field associated with it; these fields are "fuzzy" and overlap, and they may be arbitrarily expanded or contracted by the use of ever more general words or by becoming ever more detailed and explicit. Thus, the semantic realm has properties that are somewhat similar to those of the number line (which is analagous to the semantic realm of the language of numbers). The semantic realm of language is also a continuum (not a collection of discrete items), and this continuum, just as the one called the number line, is itself a mental construct. (For further elaboration of this line of thinking, see Benacerraf and Putnam, 1964; Lenneberg, 1971; Piaget, 1971; Weyl, 1948.)

Nevertheless, language and arithmetic are both also tied to the real world. Tables and chairs, aunts and uncles, sins and blessings may be counted, and consequently numbers refer to realities of various kinds; and physical things we sit at or on are unquestionably tables and chairs, respectively. There is no contradiction here between this statement and the previous one that the semantic realms of these languages are mental constructs. Inches or centimeters refer also to real things and at the same time are man-made constructs.

In order to understand the nature of language, it is first of all necessary to rid ourselves of the notion that its most important components are simply labels or "names." Language is relational in every aspect and at every term. Hence to teach someone to speak is essentially *to invite him to relate aspects of the environment in such and such a way.* The language community induces the child to treat what is before him in quantitative, qualitative, comparative terms; induces him to say something that relates an object to its use, or to the speaker, or to the listener, or to another object. In order for such an *invitation to relate* to be successful, the subject must have a natural inclination to deal with his environment in certain ways. He must be able to carry out operations upon what he sees or touches and be able to compute the sorts of relations that are reported on in lauguage as well as in arithmetic. The conception of language as a dynamic, computational *activity* should be kept in mind throughout our subsequent discussions. For instance, when we describe the natural, biological history of language development, we are really describing the gradual emergence of certain physiological processes that are the basis for computational activity. The nature of these processes becomes more and more specialized or distinct by an embryogenic process of differentiation, entirely comparable to the differentiation of cellular function and anatomic structure.

Similarly, when we review recent investigations on lauguage development, it may be well to keep in mind that the investigators are describing the behavior of immature human beings, whose mentality is undergoing growth by maturation and differentiation. Their early utterances are not simply erroneous adult sentences (such as an adult person's first steps in a foreign language), but, in fact, reflect primitive, undifferentiated computational activities.

Finally, our notions of the nature of language have a direct hearing on practical problems in language development. We may illustrate this particularly well through the arithmetic parallels. For instance, the utterance of number words or the imitation of arithmetic sentences is insufficient evidence of the attainment of arithmetic knowledge. And a patient who can recite television commercials has not given us evidence of his understanding of language; to demonstrate such understanding, he must respond correctly to commands such as "Put the box under the table," or questions such as "Is a chair something one can eat?" On the other hand, a subject's behavior may give evidence that his mental activity is essentially similar to that underlying arithmetic, yet he may at that time be ignorant of the "lexicon and syntax" of standard arithmetic. This is the case of the savage who has 15 children but in whose language there are words only for 1, 2, and 3. Nevertheless, he is capable of going to the field and collecting exactly two bananas for each child, and if he loses some of his load when falling into the river, he may ascertain

readily just how many more bananas he must still fetch to keep his brood satisfied. He might perform the task by counting on his fingers and toes or by giving every pair of bananas the name of one of his children, or by any of several other means, for all we care. We would attribute to him at least the *capacity* for arithmetic knowledge from observing his relational activities, which have resulted in a correct quantitative solution of a given problem. A language parallel may be found in a congenitally deaf child prior to language training, who may give behavioral evidence of logical operations (Oléron, 1953). These two examples suffice to show how the dynamic conception of language advocated here has a direct bearing, for instance, on clinical testing for language capacity as well as on rehabilitation procedures.

Biological Factors in Language Development

Genetic Background

Man is an unsatisfactory subject for the study of genetic influences; we cannot do breeding experiments on him and can use only statistical controls. Practically any evidence adduced is susceptible to a variety of interpretations. Nevertheless, there are indications that inheritance is at least partially responsible for deviations in verbal skills, as in the familial occurrence of a deficit termed congenital language disability (for details, see Lenneberg, 1967). Studies, with complete pedigrees, have been published on the occurrence and distribution of stuttering, of hyperfluencies, of voice qualities, and of many other traits, which constitute supporting, though not conclusive, evidence that inheritance plays a role in language acquisition. In addition to such family studies,

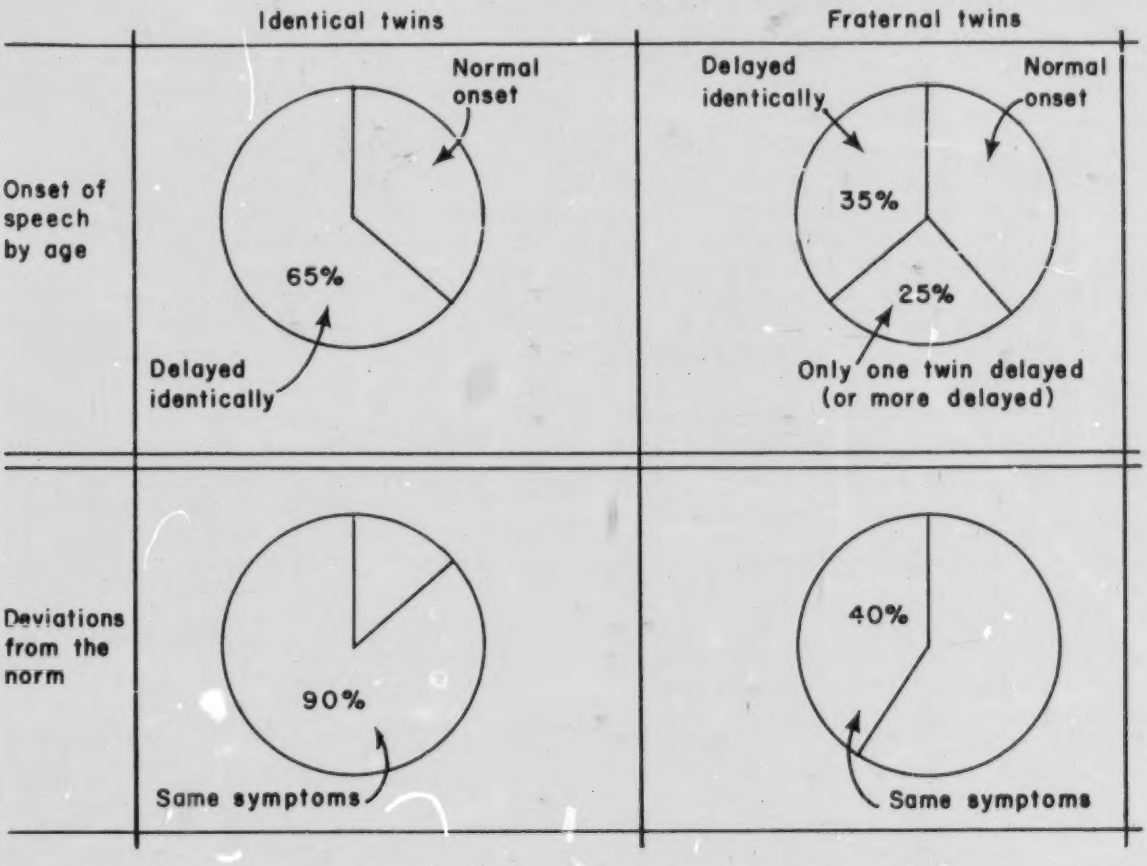

Figure 18.—The onset of speech and its subsequent development tend to be more uniform among identical twins than fraternal twins.

much research has been carried out on twins. Particularly notable are the studies of Luchsinger (1970), who reported on the concordance of developmental histories and of many aspects of speech and language. Zygosis was established in these cases (figure 18) by serology. Developmental data of this kind are, in my opinion, of greater relevance to our speculations on genetic background than are pedigrees.

The nonbiologist frequently and mistakenly thinks of genes as being directly responsible for one property or another; this leads him to the fallacy, especially when behavior is concerned, of dichotomizing everything as being dependent on either genes or environment. Genes act merely on intracellular biochemical processes, although these processes have indirect effects on events in the individual's developmental history. Many alterations in structure and function indirectly attributable to genes are more immediately the consequence of alterations in the schedule of developmental events. Therefore, the studies on twins are important in that they show that identical twins reach milestones in language development at the same age, in contrast to fraternal twins, in whom divergences are relatively common. It is also interesting that the nature of the deviations—the symptoms, if you wish—are, in the vast majority, the same in the identical twins but not in the fraternal ones. Although the existing evidence is confined to language defects, one is still tempted to presume that the normal development of language capacities is also related to developmental programs under the indirect control of genes (see Monod, 1970). Apparently the human brain, that is, its cells, tissues, and functions, differentiates into a more and more complex mechanism that eventually can perform "language-specific computations," given the necessary environmental incitement. The capacity for language development thus goes back to genetic endowment, but from this one must not conclude that there are "genes for language," nor that the environment is of no consequence for language development.

Is Language Tied to Physical Maturation?

It is well known that language capacities develop at a fairly predictable age. More impressive than the relative age-constancy of the onset of speech is the remarkable synchronization of speech milestones with motor-developmental milestones, summarized in table 2.

The temporal interlocking of speech milestones and motor milestones is not a logical necessity. There are reasons to believe that the onset of language is not simply the consequence of motor control. The development of language is quite independent of articulatory skills (Lenneberg, 1962), and the perfection of articulation cannot be predicted simply on the basis of general motor development. There are certain indications of the existence of a peculiar, language-specific maturational schedule. Many children have learned a word or two before they start to toddle, and thus must be assumed to possess a sufficient degree of motor skill to articulate, however primitively; yet the expansion of their vocabulary is still an extremely slow process. Why could they not rapidly increase their lexicon with "sloppy" sound-symbols, much the way a child with a cleft palate does at age 3? Similarly, parents' inability to train their children at this stage to join the worsts *daddy* and *bye-bye* into a single utterance cannot be explained on the grounds of motor incompetence, because at the same age children babble for periods as long as the duration of a sentence. In fact, the babbled "sentence" may be produced complete with intonation patterns. The retarding factor for language acquisition here must be a psychological one, or perhaps better, a cognitive one—not mechanical skill. About age 3 manual skills show improved coordination over earlier periods, but dexterity is still very immature on an absolute scale. Speech, which requires infinitely precise and swift movements of tongue and lips, all well-coordinated with laryngeal and respiratory motor systems, is all but fully developed when most other mechanical skills are far below their levels of future accomplishment. Various motor skills and motor coordinations also have specific maturational histories; the specific history for speech control, however, stands apart dramatically from histories of finger and hand control.

The independence of language development from motor coordination is also underscored by the priority of language comprehension over language production. Ordinarily the former precedes the latter by a matter of a few months

TABLE 2.—Correlation of Motor and Language Development

Age (years)	Motor milestones	Language milestones
½	Sits using hands for support; unilateral reaching	Cooing sounds change to babbling by introduction of consonantal sounds
1	Stands; walks when held by one hand	Syllabic reduplication; signs of understanding some words; applies some sounds regularly to signify persons or objects, that is, the first words
1 ½	Prehension and release fully developed; gait propulsive; creeps downstairs backward	Repertoire of 3 to 50 words not joined in phrases; trains of sounds and intonation patterns resembling discourse; good progress in understanding
2	Runs (with falls); walks stairs with one foot forward only	More than 50 words; two-word phrases most common; more interest in verbal communication; no more babbling
2 ½	Jumps with both feet; stands on one foot for one second; builds tower of six cubes	Every day new words; utterances of three and more words; seems to understand almost everything said to him; still many grammatical deviations
3	Tiptoes 3 yards (2.7 meters); walks stairs with alternating feet; jumps 0.9 meter	Vocabulary of some 1,000 words; about 80 percent intelligibility; grammar of utterances close approximation to colloquial adult; syntactic mistakes fewer in variety, systematic, predictable
4 ½	Jumps over rope; hops on one foot; walks on line	Language well-established; grammatical anomalies restricted either to unusual constructions or to the more literate aspects of discourse

(especially between the ages of 18 and 36 months). In certain cases this gap may be magnified by many years (Lenneberg, 1964). Careful and detailed investigations of the development of understanding by itself have been undertaken in recent years (Brown and Bellugi, 1964; Ervin, 1964; Ervin and Miller, 1963; Shipley, Smith, and Gleitman, 1969). The evidence collected so far leaves little doubt that there is also an orderly and constant progression in this aspect of language development.

The development of children with various abnormalities provides the most convincing demonstration that the onset of language is regulated by a maturational process, much the way the onset of gait is dependent upon such a process, but that the language-maturational process is independent of motor-skeletal maturation. In hypotonic children, for instance, the musculature in general is weak, and tendon reflexes are less active than normal. Hypotonia may be an isolated phenomenon that is quickly outgrown or a sign of a disease such as muscular atrophy, which would have unfortunate effects on the child's future motor development. Whatever the cause, the muscular development alone may be lagging behind other developmental aspects and thus disarrange the normal intercalation of the various processes. Here, then, speech and language emerge at their usual time, while motor development lags behind.

On the other hand, there are some children with normal intelligence and normal skeletal and motor development whose speech development alone is markedly delayed. We are not referring here to children who never learn to speak adequately because of acquired or congenital abnormalities in the brain, but rather of those who are simply late speakers, who do not begin to speak in phrases until after age 4, who have no neurological or psychiatric symptoms that can explain the delay, and whose environment appears to be adequate. The incidence of such cases is small (less than 1 in 100), but their very existence underscores the independence of language-maturational processes from other processes.

There are also conditions that affect all developmental processes simultaneously. These are diseases in which growth and maturation are retarded or stunted through a variety of factors (for instance, of an endocrine nature

as in hypothyroidism); or retardation may be due to an intracellular abnormality such as the chromosomal disorder causing mongolism. In these cases all processes suffer alike, resulting in general "stretching" of the developmental time scale, but leaving the intercalation of motor and speech milestones intact (Lenneberg, Nichols, and Rosenberger, 1964). The preservation of synchrony between motor and speech or language milestones in cases of general retardation is, I believe, the most cogent evidence that language acquisition is regulated by maturational phenomena.

The evidence presented rules out the possibility of a direct, causal relationship between motor and speech development. Normally, growth and maturation proceed at characteristic rates for each developmental aspect. In the absence of specific retardations affecting skills or organs differentially, a picture of consistency evolves such as is represented in table 2 or in the many accounts of normal human development (McGraw, 1963; Gesell and Amatruda, 1947).

Just the same, individual differences in time of onset and reaching of various milestones do exist. The rate of development is not constant during the formative years, and there may be transient slowing in the rate of maturation, with subsequent hastening. This is hardly surprising in view of the complex interrelation of intrinsic and extrinsic factors that affect development. Nevertheless, there is a remarkable degree of regularity in the emergence of language.

Sensitive Age for Language Acquisition

Since language acquisition is paced by underlying maturational processes, it is possible *either* that a capacity becomes ready during ontogeny that remains potent throughout life, *or* that the capacity is a phase during developmental history with a beginning and an end. The question here is not whether environmental stimulation plays a role in language acquisition (it is obvious that it does), but whether environmental stimulation remains equally effective once a basic level of maturation has been reached. If it should be true that the effectiveness declines (say after the age of 14 or 15), this would have an important bearing on educational programs. At least three types of evidence support the hypothesis that the capacity for primary language acquisition is optimal between the ages of, roughly, 2 years and the early teens.[2]

(1) *Recovery From Acquired Aphasia.* The most revealing evidence of an age limitation in language acquisition is provided by adventitious language disorders. The chances for recovery from acquired aphasia are different for children than for adult patients, the prognosis being directly related to the age at which insult to the brain is incurred. To illustrate this difference, let us first describe the recovery patterns for adult patients.

The patient with aphasia has not, strictly speaking, lost his language habits the way we may "lose" a poem, once memorized and now forgotten. Nor is his cognitive state comparable to that of the 20-month-old infant before the advent of language learning. Usually, there is evidence that language is not lost, but that its proper organization, in either the expressive or the receptive process or both, is interfered with. He cannot organize his cognitive activities to recruit, integrate, or inhibit the many partial processes that, when consolidated, are prerequisite for speaking and understanding. Yet, shreds of the earlier language behavior usually persist, although there are some patients who can say no more than a few words, and sometimes even these few utterances may be unintelligible jargon.

The adult patient does not relearn language. Neither training nor conditioning procedures are guarantees of the restoration of language to the patient with a well-established aphasia. This is understandable, because his problem is not that he does not know language but that he can no longer make use of language that he has learned. A patient with aphasia has not lost other, more general abilities to learn; he is not demented and not psychotic; he may continue to make new associations, to build up new expectations, to make new inferences and, generally, to give signs that his nonspe-

[2] Notice that the upper limit of "early teens" is actually quite conservative. In the light of the evidence cited by Fry (1966), and in view of what is now known about the early maturation of the brain, it is likely that the preschool years are the most important ones for environmental influences upon good language development.

cific learning capacities have not come to an end. Thus, the language disorder is not a learning impairment.

Aphasias acquired during adult life, that is, after the age of 18 years, may recover within a 3- to 5-month period. There are reasons to believe that this is due to physiological restoration of function rather than to a learning process. Symptoms that have not cleared up by this time are, as a rule, irreversible.

There are a few clinical exceptions to this picture (Woodward, 1945; and two cases alluded to in Marks, Taylor, and Rusk, 1957). Speech disturbances resulting from anoxic states often disappear more gradually, with recovery periods extending over a year or more. Furthermore, aphasia is often accompanied by emotional depression. If this is the case, speech rehabilitation may work wonders by instilling confidence and by encouraging the patient to explore all his remaining potentialities; he may learn to compensate for certain losses by recruiting skills not ordinarily part of the speech and language act. The 5-months' rule previously mentioned holds true for the basic capacities for verbal communication.

When aphasic symptoms subside in the adult patient, he does not traverse the infant's stages of language learning. There is no babbling, single-word stage followed by a two-word-phrase stage. There is no semantic overgeneralization nor a gradual emergence of the more complex grammatical constructions.

Compare now aphasia in childhood. We shall consider only children who were in possession of language before the catastrophe and who suffered a one-sided lesion.

The aphasic symptoms seen in the adult traumatized patient may also be observed in children with comparable lesions. The only possible exception is the so-called fluency aphasia or "logorrhea," in which the patient is either unable or unwilling to inhibit his flow of speech, producing a continuous train of semantically disconnected phrases or sentences. This symptom is rare or perhaps altogether absent among pediatric patients. Otherwise, the general characterization of aphasia as interference with existing verbal habits also applies to this group. However, there are other important differences between children and adult aphasics. If the aphasia occurs early in life, for example at age 4, two processes intermingle so intensely during the recovery period that a rather different clinical picture emerges. The two processes are the interference phenomena caused by the lesion and the extremely active language-learning process that may not be inhibited at all by the disease or may only very temporarily come to an arrest, soon to be reinstated.

In contrast to the adult patient, the overwhelming majority of children age 4 to 10 recover fully and have no aphasic residue in later life (even though some individuals may always retain minor cognitive or perceptual deficits that may or may not be related to language; Teuber, 1950, 1960). Further, the period during which recovery from aphasia takes place may last much longer than in the adult. Instead of the adult trend toward a 5-months' period of improvement, children may show steady improvement over a period of several years, although usually not after puberty. Language deficits outlasting puberty, especially those that have persisted for a number of years, are usually irreversible.

If aphasia strikes the very young, during or immediately after the age at which language is acquired (between 20 and 36 months of age), the recovery is yet different. Cerebral trauma to the 2- or 3-year-old will render the patient totally unresponsive, sometimes for weeks at a time; when he becomes cognizant of his environment again, it becomes clear that whatever beginning he had made in language before the disease is totally lost. Soon, however, he will start again on the road toward language acquisition, traversing all stages of infant vocalization, perhaps at a slightly faster pace, beginning with babbling, single words, primitive two-word phrases, etc., until perfect speech is achieved. In the very young, then, the primary process in recovery is *acquisition*, whereas the process of symptom-reduction is not in evidence.

In summary, between the ages of 3 and 4, language learning and language interference may compete for a few weeks, but within a short period of time, the aphasic handicap is overcome. In patients older than 4 and younger than 10, the clinical picture is that of a typical aphasia that gradually subsides. At the same time, the child appears to have no difficulty expanding his vocabulary and

learning new and complex grammatical constructions. By the time of puberty, a turning point is reached. Aphasias that develop from this age on, or that have not had time to clear up completely by this stage, commonly leave some trace behind, which the patient cannot overcome. These youngsters characteristically regain language and can carry on a conversation; but there will be odd hesitation pauses, searching for words, or the utterance of an inappropriate word or sound sequence that cannot be inhibited. Emotional tension magnifies the symptoms, making their aphasic nature very obvious. In the middle teens, the prognosis for recovery rapidly becomes the same as that for the adult patient.

(2) *The Natural History of Cerebral Lateralization.* Acquired brain lesions also give us a clue to the developmental history of cerebral lateralization. A left-sided lesion acquired before the age of 2 has no effect on subsequent language development. Apparently at this age the right hemisphere may become as useful for language processes as the left hemisphere usually is. Left-sided lesions acquired between the ages of 3 and 10, however, begin to compromise speech function (in the manner described) with increasing frequency. There is also evidence that the peculiar specialization of the left hemisphere may be blocked by the early presence of epileptogenic lesions in the left. Unfortunately, we do not have well enough documented cases to be able to plot out exactly the critical ages for these events; it is certain that congenital fixed abnormalities in the left hemisphere prevent left lateralizations; whether epileptogenic foci acquired later but before 10 have a similar effect remains to be established, though it is not unlikely.

When lateralization is blocked, it will be the right hemisphere that subserves speech function for the rest of the individual's life. This view is corroborated from experience with left hemispherectomy (surgical removal of a cerebral hemisphere). Removal of the left hemisphere in an adult with normal developmental history produces a dense aphasia in over 90 percent of all cases. However, if the left hemisphere is removed in an adult patient who has suffered since early childhood from abnormal cerebral function (producing uncontrollable seizure activities), the source of the disease is removed but not the mechanisms that carry out language functions in such a patient. Thus it becomes fairly obvious that even the anatomical-physiological substrate for language only differentiates embryologically after about the second year of life, and that the immature tissues do not become embryologically *determined* till later on. The plasticity that prevails until the early teens is comparable to a phenomenon called *regulation* by neuroembryologists. Regulation is no longer possible once determination is completed, at the time that the anatomical-physiological substrate is "locked into place," so to speak. This conceptualization explains nicely the clinical variations of traumatic aphasia and their dependence upon age. Moreover, it receives considerable support from a survey of language development among retardates.

(3) *Arrest of Language Development in the Retarded.* The material reviewed might give the impression that the age limitation is primarily due to better recovery from disease in childhood, and that the language limitations are only a secondary effect. This is probably not so. In a study by Lenneberg, Nichols, and Rosenberger (1964), 54 mongoloids (all raised at home) were seen 2 or 3 times a year over a 3-year period. The age range was from 6 months to 22 years. The appearance of motor milestones and the onset of speech differed considerably from individual to individual, but all made some progress—although very slow in many cases—before they reached their early teens. This was true of motor development as well as of speech. In all children seen in this study, stance, gait, and fine coordination of hands and fingers was acquired before the end of the first decade. At the close of the study, 75 percent had reached at least the first stage of language development; they had a small vocabulary and could execute simple spoken commands. But interestingly enough, progress in language development was only recorded in children younger than 14. Cases in their later teens were the same in terms of their language development at the beginning as at the end of the study. The observation seems to indicate that even in the absence of gross structural brain lesions, progress in language learning

comes to a standstill after maturity (see also Lackner, 1968). In some retardates sexual puberty is delayed by several years. For instance, in Downe's syndrome menarche may occur anywhere between 12 and 20 years of age. Unfortunately this is not an indication that the optimal period for language acquisition is necessarily prolonged accordingly. It is difficult to make exact predictions at what age and for what length of time an individual retarded patient is most likely to make progress in language development. Onset of speech is regulated by maturational processes; the end of the critical period is apparently correlated with the time at which the brain stops developing. Since it is difficult to ascertain when this will occur in a specific abnormally developing child and since there is a chance that it will happen much sooner than sexual maturity in these patients, the educator is well advised to do as much for each child as possible as soon as he or she has begun to show an interest in language.

We might mention in passing that Fry (1966) has observed a dramatic difference in the effectiveness of special training in the congenitally deaf. In his study, the critical time for rehabilitation was even more restricted than that postulated here, the optimal period for articulation training coming to a close shortly after age 3.

In concluding this section, we must draw the reader's attention to the fact that we are concerned here only with the possibility of transforming a mere capacity for language into the actual exercise of language—in short, with primary language development. The concept of "sensitive period" refers only to this—not to the learning of "foreign languages" later in life. Once the cognitive activities underlying language in general have been established, the human mind seems capable of transferring the skills from the native tongue to other natural languages.

Brain Maturation

The cited developmental evidence clearly indicates that the acquisition of primary language is somehow related to maturational events. This leads us logically to the question, what happens to the human brain during this period? Surprisingly little is known about developmental neurophysiology in mammals. This is particularly true of those neurophysiological events that relate directly to the ontogenetic emergence of behavior patterns. And ignorance is even more dense when it comes to human brain maturation. However, one generalization can be made that is peculiarly suggestive with respect to the language data reviewed in the previous section. If we look at such parameters as gross brain weight, growth of dendritic arborization, biochemical composition of the human cortex, etc., we find that the human brain reaches the mature values of these parameters during the early teens. In other words, our brain is essentially mature at this age, even though the rest of the body usually continues to develop for another few years, sometimes even at a relatively accelerated rate. The brain, on the other hand, goes through its fastest rate of development during the first 2 or 3 years. By this time, roughly 60 to 70 percent of mature values of most parameters have been attained. The brain continues to develop for almost another 10 years, but at an ever slower rate. Thus, the optimal period for primary language acquisition falls into a period of brain maturation when a good deal of growing has already been accomplished but when the brain has not yet come to a maturational standstill. What is suggestive about this is that the ideas of "locked-in" function and "age-conditional" plasticity might be understood as an epigenetic process in the sense of Waddington (1956). The entire argument of this and the preceding section are summarized in tables 3a and b.

Recent Studies on Language Development

Birth to 12 Months: Babbling and Phonological Development

Immediately after birth the infant vocalizes by crying and other seemingly emotional sounds. (For a summary of the earlier literature on this period, see Irwin and Chen, 1943; McCarthy, 1954.) Between the ages of 3 and 6 months, many babies begin a stage of babbling, which may last to the age of 12 months or longer. During this period the infant vocalizes by babbling speech-like repetitive sounds, as well as by cooing and crying. A wide variety of sounds can be detected in babbling, including sounds not found in the

TABLE 3a

AGE	LATERALIZATION OF FUNCTION	EQUIPOTENTIALITY OF HEMISPHERES	EXPLANATION
Months 0–3	None: symptoms and prognosis identical for either hemisphere.	Perfect equipotentiality.	Neuroanatomical and physiological prerequisites become established.
4–20			
21–36	Hand preference emerges.	Right hemisphere can easily adopt sole responsibility for language.	Language appears to involve entire brain; little cortical specialization with regard to language, though left hemisphere beginning to become dominant toward the end of this period.
Years 3–10	Cerebral dominance established between 3–5 years, but evidence that right hemisphere may often still be involved in speech and language functions. About ¼ of early childhood aphasia due to right hemisphere lesions.	In cases where language is already predominantly localized in left hemisphere and aphasia ensues with left lesion, it is possible to reestablish language, presumably by reactivating language functions in right hemisphere.	A process of physiological organization takes place in which functional lateralization of language to left is prominent. "Physiological redundancy" is gradually reduced and polarization of activities between right and left hemisphere is established. As long as maturational processes have not stopped, reorganization is still possible.
11–14	Apparently firmly established, but definitive statistics not available.	Marked signs of reduction in equipotentiality.	Language markedly lateralized and internal organization established irreversibly for life. Language-free parts of brain cannot take over; however, where lateralization is incomplete or has been blocked pathologically during childhood, the right hemisphere may remain language-competent throughout life.
Mid-teens to senium	In about 97 percent of the entire population language is definitely lateralized to the left.	None for language.	

infant's native language. As Jakobson (1968, p. 21) put it, "A child, during his babbling period, can accumulate articulations which are never found within a single language or even a group of languages—consonants of any place of articulation, palatalized and rounded consonants, sibilants, affricates, clicks, complex vowels, diphthongs, etc."

On the basis of his observations, Jakobson hypothesized a discontinuity between babbling and true word learning, each characterized by a distinct developmental sequence. He suggested a process of gradual differentiation of sounds in true word learning, with the order of differentiation of sounds universal across children of different cultures. There is some evidence to support the hypothesis of a discontinuity between babbling and word learning (cf. Velten's 1943 survey of the diary literature). Other observers, however, have found "babbling drift," a gradual progression within the babbling period toward the intonation and phonemes of the child's native language (Weir, 1966). These observations have not as yet been verified by a double-blind test. There is also conflicting evidence concerning the order of phonemic development, but there is general agreement that it proceeds through a process of finer and finer differentiation, as Jakobson proposed (see Kaplan and Kaplan, 1970, for further discussion).

Of particular interest is the development of intonation during the babbling period. Kaplan (1969) found that the ability of young chil-

TABLE 3b

AGE	USUAL LANGUAGE DEVELOPMENT	EFFECTS OF ACQUIRED, LATERALIZED LESIONS	PHYSICAL MATURATION OF CNS
Months 0–3	Emergence of cooing.	No effect on onset of language in half of all cases; other half has delayed onset but normal development.	About 60–70 percent of developmental course accomplished.
4–20	From babbling to words.		
21–36	Acquisition of basic principles of language.	All language accomplishments disappear; language is reacquired with repetition of all stages.	Rate of maturation slowed down.
Years 3–10	Grammatical refinement; expansion of vocabulary.	Emergence of aphasic symptoms; disorders tend to recover without residual language deficits (except in reading or writing). During recovery period two processes active: diminishing asphasic interference and further acquisition of language.	Very slow completion of maturational processes.
11–14	Foreign accents emerge in second language.	Some aphasic symptoms become irreversible (particularly when acquired lesion was traumatic).	An asymptote is reached on almost all parameters. Exceptions are myelinization and EEG spectrum.
Mid-teens to senium	Acquisition of second language becomes increasingly difficult.	Symptoms present after 3–5 months postinsult are irreversible.	None.

dren to discriminate between different intonation patterns develops between the ages of 4 and 8 months. Weir (1966) reported intonation differences between the babbling of Chinese infants and that of Russian and American infants by the age of 6 months. Such early perception and production of different intonation patterns by infants is suggestive, because intonation patterns signal differences between statements, exclamations, and questions. It is clearly adaptive for the young child to detect this cue to the intentions of the speakers around him.

It is possible to speculate that, in addition to a gradual development of such features as intonation, the child's vocalization during the first year should show gradual development in another direction, that of increased meaningfulness. The early cries show limited meaningfulness, as they convey merely the general emotional state of the infant. There are observations in the literature that suggest that even before the stage of clearly defined words, the child makes sounds that indicate particular situations. For example, Preyer's son at 6 months used "orro" to indicate contentment (Preyer, 1889, p. 106). The same child used "atta" at 11 months when he saw something disappear, and "a-na" at 12 months as a sign of desire (pp. 111–112). These observations suggest that the child begins to apply his vocalizations to particular situations or events around him before he knows the words adults apply to these situations. Unfortunately, ob-

servations of children's speech at this age are so far primarily anecdotal.

An important question concerns the role of babbling in language learning. Some theorists have seen the period of babbling and early phonological development as a process of continual reinforcement by the parents, which rewards the child's "correct" sounds and guides him to make more "correct" sounds. However, as Lenneberg (1966, 1967) pointed out, some children omit completely the babbling period, yet develop fluent speech in due time. Thus if babbling is indeed a "practice period" for the development of language sounds, then it is surely optional rather than obligatory.

One-Word Utterances: 12 to 18 Months

In most children, the most striking changes in language acquisition after the 12th month of age are semantic and grammatical. The stage of one-word utterances is initiated by the child's production of the first word, generally around the age of 12 months. This is rapidly followed by the learning of other words (see McCarthy, 1954, for a summary). The one-word utterances produced during this period are often referred to as "holophrastic," as representing complete thoughts in a one-word sentence (McNeill, 1970). According to this view, subsequent development fills in omissions as the memory span and lexicon of the child increase. Although others have disputed this position (Bloom, 1971), the debate can only be resolved by much more evidence than is available at this time.

Attempts to classify one-word utterances have been based largely on the functions that the words seem to serve in the context. For McNeill (1970), one-word utterances serve three functions: conative—speech that accompanies or initiates actions, such as commands; expressive—speech that indicates emotional reactions; and referential—speech used to label or name. Although this is a traditional classification of speech functions, dating back to Bühler (1926), there is no particular reason to assume that it is the best possible classification.

The use of words as labels during this period is especially interesting. It is possible to use the child's errors in his use of words to infer the categories he has formed (Clark, 1971a). The early diary studies show that many of the errors of reference during the one-word stage are overgeneralizations. Lewis (1936) describes Stern's classification of different cases in which overgeneralization occurs: (1) Similarity of the whole situations; e.g., when a child applies the word for "moon" to any round object. (2) Similarity of certain features—e.g., Lewis' child at 2;2 used/kotibaiz/for an abacus with parallel rows of beads; at 2;4 he applied it to a toast rack with parallel bars and also to a picture of a building with columns. This example is especially interesting because the child's apparent concept of "things with parallel bars" is not coded by a single label in English. (3) Similarity based on shifting from feature to feature; e.g., as in Romanes' classic example of a boy who used "quack" for a duck, then for the picture of an eagle on a coin, then for coins in general. Lewis notes that although these situations all depend on objective similarity, it is also possible to find examples of overgeneralization based on affective and functional similarity. For example, Stern's daughter Hilde used "puppe" for many toys, such as a doll and a toy cat, that were dissimilar except as objects of play.

There are also examples in the diary studies of undergeneralization. Leopold's daughter Hildegarde at 1;10 knew the word "hot" for radiators and flames, but was puzzled when her father used it to refer to the temperature of the air in a room. She had not yet extended the concept beyond the temperature of tangible bodies.

These examples of errors in early word learning are important as a clue to the cognitive structure of the child, that is, the system of concepts he is developing. Leopold (1949) gives an example of Hildegard's use of "tick-tock." She first applied this at 11 months to wrist watches, then gradually extended it to name clocks, a gas meter, bathroom scales, a firehose wound on a spool, and a round eraser. It is clear that she had a concept of "round things" or "things with round dials" that functioned as a referent for "tick-tock." This is not a concept that is coded by a single word label in adult English. What then is the fate of this concept? Does it become less salient as the child learns that it is not directly coded

by an English word." There is evidence (Deese, 1967) that adults have little difficulty in learning such concepts. More research is needed on the development of language and concepts. It cannot be emphasized too strongly that the problem of learning word meanings is not a simple matter of associating a sound sequence with an object or event. Naming an object or event is based on the perception of complex relations such as similarity, identity, and causality—relations that enable the child to form categories and classes that are then organized linguistically.

Brown (1958) discussed the development of categories in children's speech. He argued for increasingly finer differentiation of words at varying levels of generality; for example, a child might first learn "dog," then gradually learn names for different breeds of dogs as he needed such names. There is, however, another interesting problem, which this argument does not cover. Why do children use some word classes rather than others during the single word stage? Although data on this point are meager, the available evidence (e.g., Bloom, 1970) shows a preponderance of nouns and verbs over adjectives, pronouns, prepositions, or conjunctions. A clue is provided by Jean Berko Gleason's experiment (see Brown, 1957), showing that 3- to 5-year-old children knew the semantic correlates of nouns and verbs. A sentence was given to each child, such as "Do you know what it means to sib?" Then the child was shown a picture containing an object, a mass substance, and an activity. The children more often pointed to the action in the picture when the nonsense word was a verb, as above, and to an object in the picture when the nonsense word was a noun. It seems especially important for children to learn the categories of objects and events, corresponding to nouns and verbs, as these are the basic categories around which sentences are structured. The children in this experiment, however, were past the single-word stage.

Bloom (1971) has presented evidence to show that the stage of single-word utterances, rather than being a period of no change, shows a sequence of developmental changes. In her observations of her daughter, Bloom found a trend around 18 months toward sequences of single-word utterances. These could be distinguished from syntactic combinations by the separate terminal pitch and relatively equal stress on each word. These sequences, such as "car see," seemed to express some relation between successive words, suggesting that the child's understanding of relations in the world may outrun his ability to express them linguistically. Bloom also notes other changes within the single-word period, including a trend toward the use of more verbs and more names as agents around the age of 17 months. Unfortunately, there is no methodology available for the study of these changes except for such subjective classification of words as according to functions, relations, or parts of speech.

Stage of Two-Word Utterances: 18 Months

At about the age of 18 to 22 months, the child passes another key milestone in language acquisition, as he begins to combine words into two-word utterances. These syntactic sequences can be distinguished from sequences of single-word utterances by their phrase-like intonation, rather than a separate, list-like intonation for each word. For example, Menyuk (1969) reports on a child whose earliest two-word utterances (at 20 months) showed three different intonation patterns, either (.), (?), or (!). A more difficult task is to distinguish two-word utterances from three-word and longer utterances, which begin to appear, although infrequently, as soon as two-word utterances. The difficulty is due to certain combinations, such as "allgone," which consist of two adult words but which seem to occur invariably as one word in the child's speech.

The earliest attempts to write descriptive grammars for children's two-word utterances were based on the method of privilege of occurrence: that is, words that occurred in the same position in the utterance were assumed to be members of the same class. When this analysis was applied to the available data, it suggested a division of the children's vocabulary into two classes: a "pivot" class, consisting of a small number of words that could combine with any one of a large number of words; and the "open" class (Braine, 1963).

Although the pivot-open distinction is still used as a means of describing the speech of particular children (see Bloom, 1970), it has

been largely discarded in favor of other descriptions (Brown, 1970a and b). There were two limitations of pivot-open grammars that led to this change. On the one hand, the pivot-open analysis was based solely on structure; the meaning of the words was disregarded. Attempts to include meaning in the analysis by examining the situational context led to the analyses of Bloom. (1970) and Schlesinger (1971), which will be discussed below. The other problem concerned pivot-open grammars as a stage in the development of adult form classes. As McNeill (1966) pointed out, the pivot and open classes are not always homogeneous. For example, Izanami, McNeill's subject, used adjectives in both pivot and open positions. Thus, McNeill comments, "Izanami will have to recombine P and O classes in order to obtain a single class of adjectives" (1966, p. 112). This led McNeill to propose that the pivot-open distinction is superficial, reflecting a deeper distinction between noun phrase-predicate or modified-head. This suggestion is not incompatible with the "semantic grammars" of Bloom and Schlesinger.

The analysis of Bloom (1970) differed in two important ways from previous work on two-word utterances. She included as part of her data a description of the situation or context in which the utterance occurred. This is in contrast to the earlier data, which included context only in cases of special ambiguity. Furthermore, Bloom used this record of the context to interpret and classify children's utterances according to the functional relations or "semantic intention" expressed in the utterance. At about the same time, Schlesinger (1971) independently classified the relations in two-word utterances, developing a list that corresponds fairly closely to Bloom's (see table 4).

The "semantic classifications" of Bloom and Schlesinger represent an important advance over the earlier analyses of two-word utterances. They are particularly interesting as they relate to the child's cognitive and perceptual development; the relations expressed in the child's speech during this stage seem to be very close to certain cognitive and perceptual relations. For example, Bloom describes the relations of notice, nonexistence, and recurrence (or appearance, disappearance, and reappearance), which depend on the concept of object permanence.

There are difficult methodological problems with the interpretation of children's early utterances. In some ways, the task of the student of language acquisition is similar to that of the student of animal behavior: in each case, the subject cannot introspect or answer questions about his behavior. Rather, the experimenter must relay on observing and classifying the behavior in a meaningful way. Bloom improved on earlier methodology by including a record of the context, but no one has yet developed a methodology for classifying children's utterances that is not open to the charge of arbitrariness. Even though Bloom and Schlesinger independently produced similar lists of relations, there were discrepancies between them—for example, Bloom subdivided more than Schlesinger. Moreover, concordance be-

TABLE 4

SAMPLE UTTERANCES		RELATIONS	
Bloom	Schlesinger	Bloom	Schlesinger
Hi shadow	Here bed	Notice	Ostension
More raisin	More nut	Recurrence	Modifier-head
Mommy slipper	My stool	Genitive	
Party hat	Big boat	Attributive	
Sweater chair	Baby room	Locative	Locative
Mommy diaper	Eve lunch	Subject-object	Agent-object
Mommy push	Mail come	Subject-predicate	Agent-action
———	See sock	———	Action-object
Umbrella boot	———	Conjunction	———
No more light	Isn't . . .	Nonexistence	Negation
No dirty soap	No down	Rejection	
No truck	No wet	Denial	

tween the classifications may very well be due to convictions shared by the entire academic community, rather than due to facts of nature.

One recent proposal has been to develop a theory of complexity, either grammatical or semantic, as a model against which to compare the course of language acquisition (Slobin, 1971b). Brown (1970b) studied the order of acquisition of 14 selected forms, including prepositions, articles, and inflections. Using a criterion of 90 percent of potential usage as a measure for acquisition, Brown found a consistent order of acquisition of the 14 forms across the 3 children studied. There was no correlation between the order of acquisition of the morphemes and their frequency of occurrence in parental speech. However, Brown also examined certain syntactic and semantic variables in an attempt to formulate a theory of linguistic complexity, and found these to correlate more closely with the order of emergence of the morphemes. Unfortunately, no comparable studies have been reported as yet for retarded or deaf children.

Another aspect of two-word utterances recently studied is sequential word order. Slobin reports that children speaking languages as diverse as German, Russian, Samoan, and Luo generally follow the adult order in their two-word utterances. He cites in particular the case of Gvozdev's child: "Even in Russian, where the highly inflected adult language allows for considerable freedom of word order, word order in the utterances of the one child studied in detail was quite stable" (1971a, p. 4). Brown also reports that children generally preserve the word order of adult English. In the studies he summarizes: "The reported violations of normal word order are triflingly few. . . . Of utterances in normal order there are many thousands" (1970a, p. 110). The implication of this fact is unclear; Slobin (1971a) proposes that a universal strategy for children learning to speak is to attend to word order, but this will require more evidence.

Beyond Two-Word Utterances

As the child begins to produce longer sentences and to approach adult word classes more closely, his language rapidly becomes too complex to be described in a simple minded analysis. One approach to the study of this stage has been to write a series of transformational grammars for different levels of development (Menyuk, 1969; Brown, Cazden, and Bellugi, 1968). These grammars are based on a particular formulation of grammatical theory; thus, they make special assumptions about the relation between the utterance and the speaker's knowledge that may not necessarily be appropriate for developing language. The adult speaker can make judgments about his language that are separate from his normal speech behavior; the linguistic knowledge of the child can be studied only through observation of his linguistic behavior—production, imitation, and comprehension. The transformational grammars of child language also convert an ongoing process into a series of static stages. This may possibly be a misleading method of studying language processes.

A group of studies have looked at the interaction between the child's speech and that of his parents, especially in his imitations. There is scattered evidence (see Brown, 1970a) that parents use shorter and simpler sentences when talking to children, which may simplify the task of the child in learning to speak. There is also evidence that the child's progress in language acquisition does not depend on reinforcement by the parents of correct utterances. Brown and Hanlon (1970) report that parents make the same number of responses to both well-formed and primitive utterances of their children. Progress in language acquisition also does not seem to depend on imitation. In general, very young children imitate poorly, either echoing the last few words they hear or reducing the sentence to a two- or three-word utterance (Brown and Bellugi, 1964). Ervin (1964) found that at age 2, 80 percent of children's imitations conform to the child's own grammar at that stage, indicating that imitation is not grammatically progressive and probably does not lead to better production. Fraser, Brown, and Bellugi (1963) found imitation at 3 to 4 years to be accurate, whereas Menyuk (1963) found that nursery school and kindergarten children could not accurately imitate many forms produced by other children, but instead repeated the correct adult form. This is an interesting result, since the children themselves produced many

of the same incorrect forms in their spontaneous speech.

There is little evidence on the relation between comprehension and production. The generally accepted view is that children comprehend structures before they can produce them (Fraser, Brown, and Bellugi, 1963). McNeill expresses this view when he states: "To understand linguistic development, we must understand comprehension" (1970, p. 102). Yet the bulk of the available research is based on children's spontaneous utterances. One exception is the study of Shipley, Smith, and Gleitman (1969). These experimenters gave commands to children at the one-word and two-word levels of grammatical development. The commands were either well-formed ("Throw me the ball"), telegraphic ("Throw ball"), isolated noun ("Ball"), or lengthened telegraphic ("Please, Johnnie, throw ball"). In addition, each command could be all in English (as in the above examples) or in partial nonsense ("Throw ronta ball," "Gor ball"). Children at the stage of two-word utterances obeyed more well-formed commands than telegraphic or single-noun commands, whereas children at the stage of one-word speech responded correctly to more telegraphic commands. Shipley, Smith, and Gleitman concluded that the children at the two-word stage were making discriminations that they were not yet able to produce.

Another approach is to select a particular grammatical pattern and study its development progressively. Brown's (1970b) study of 14 morphemes has been discussed already. Other experimenters have examined the development of noun and verb inflections (Cazden, 1968). There is a sequence common to many children: correct use of irregular forms ("took"), followed by overgeneralization of irregular forms to regular endings ("taked"), then use of correct endings for both regular and irregular forms. A classic study on the learning of morpheme endings is Berko's (1958) work on children ages 4 to 7, showing their growing ability to add the correct morphological endings to nonsense words.

The two sets of transformations that have been studied most thoroughly are those for negation and questions. Brown and Hanlon (1970) examined the acquisition of these forms, including yes-no questions, tag questions ("You aren't going, are you?"), negatives, truncated predicates ("I am."), and combinations of these ("The man drives well, doesn't he?). They attempted to derive a principle of cumulative complexity—given two sentences, the one that requires all the rules of the other and at least one more rule is the more complex of the two. Brown and Hanlon found this principle to predict adequately the order of development of these forms in children's speech. Klima and Bellugi (1966) wrote grammatical rules for three stages in the development of questions. At the first stage, the child has "extremely limited means" for expressing negation; Klima and Bellugi describe the rule as " 'No' or 'not' + Nucleus." The utterances of the children at this stage are simple: "No mitten" or "No sit there" (Klima and Bellugi, 1966, p. 192). These forms continue to appear even in the second and third stages, when new rules are required to account for more complex sentences. By the third stage, the child's utterances approach adult usage—"Paul can't have one" and "Don't touch the fish," as well as "I not crying" and "I not hurt him." Finally, Brown (1968) discusses the development of wh- questions, such as "What do you want?" He suggests that the typical child-form, "What John will read?" cannot be derived from simple reduction of adult speech, because the word order is wrong. Rather, the child seems to be using his own grammatical rules.

There are two detailed studies on the development of negation. Bloom (1970) described three types of negation—rejection, nonexistence, and denial. For example, when Kathryn pushed away a piece of worn soap and said "No dirty soap," Bloom classified this as an instance of rejection (1970, p. 172). An example of nonexistence occurred when Eric finished his juice and said "No more juice" (p. 172). Denial occurred when Kathryn's mother handed her a toy car, saying "There's the truck," and Kathryn answered "No truck" (p. 173). These three categories show a changing pattern of usage, with nonexistence predominating in an early stage, followed by an increase in rejection an denial, as well as gradual differentiation of forms. Klima and Bellugi (1966) also analyze the development of negation, writing grammatical rules for three stages of the development.

TABLE 5.—Important Points for Differential Diagnosis of Speech and Language Disorders

Diagnosis	Developmental History	Symptomatology	Management
Peripheral Deafness	Normal milestones; normal vocalization during first 6 months. Abnormal persistence of babble and complete absence of words.	Normal affect; gestures only but eager to communicate; plays constructively and with concentration; no reaction to sounds.	Establish diagnosis by audiogram; hearing aid; special training.
Mental Retardation	Slow but steady; motor development sometimes better than cognitive.	Comprehension slightly ahead of speech production. Language is consistent with that of a younger child and free from bizarre stereotypes. Understanding, vocabulary, syntax suffer to an equal extent.	No special measures for language rehabilitation, but make sure child is spoken to and has opportunity to practice his skills.
Childhood Psychosis	Normal for motor milestones. Progress is irregular with surprise advances or regressions; socialization defective.	Usually mutism with occasional indications that language has been acquired but motivation to speak is lacking; sometimes well-developed language but bizarre use of it; normal communication process interrupted.	Treatment is restricted to psychiatric disease. Amplification of sound is contraindicated. Articulation exercises are irrelevant.
Congenital Inarticulation	Normal milestones, except for development of vocalization.	Intelligent or slightly dull child with normal affect and good motivation for communication; certain consonants consistently omitted or distorted; voice and intonation pattern intact. In severe cases no intelligible speech at all but in all cases understanding of language is normal.	Preschool child: prevention or correction of secondary mental health problems in patient and parents. School child: assure proper instruction in reading and writing by enlightenment of teachers.
(Acquired) Aphasia	Within normal limits.	Under 4 years: short period of complete loss of language followed by rapid relearning. After 4 years: well-formed words but apraxia, word-finding difficulty, inappropriate utterances, confusion, jargon, telegraphic style.	After first 6 months of spontaneous recovery, speech rehabilitation often helps to encourage patient and restore self-confidence. If learning difficulties are associated with aphasia, academic help ought to precede articulation drill.

They find an increase in the variety of different forms used to express negation. Other studies (Menyuk, 1964 a and b; Brannon, 1968) also find sequences in the development of transformations.

There are several studies on the development of particular forms in older children. Clark (1971b) studied the acquisition of "before" and "after" in children aged 3 to 5. She described four stages in the acquisition of these forms, with children in general learning the meaning of "before" first. Donaldson and Wales (1970) examined several relational terms such as "same-different" and "more-less" in children aged 3½ to 5. In another study, children of the same age group interpreted both "less" and "more" to mean "more" (Donaldson and Balfour, 1968). Huttenlocher has described

the acquisition of children's comprehension of relations in sentences, such as grammatical subject and logical subject (Huttenlocher and Strauss, 1968; Huttenlocher, Eisenberg, and Strauss, 1968). Turner and Rommetveit (1967 a and b) examined the use of passive sentences by children ages 4 through 9, and found an increase in the use of the correct form of the passive voice during this period. By the age of 9, children made few errors in the use of the passive. Finally, Carol Chomsky (1969) studied four structures: "easy to see," "ask-tell," "promise-tell," and pronominalization, in children aged 5 through 10. She created situations involving these forms and asked the children to respond to questions about the situations, thereby measuring their comprehension of the forms. Chomsky attempted to predict the order of acquisition of the forms on the basis of linguistic principles of complexity. Her work is valuable, as it demonstrates that learning of grammatical forms continues until school age and beyond.

Conclusion

In the practice of verbal intercourse, relations of various kinds are assessed and reported on. In language comprehension, the subject accedes to an invitation to bring objects into prescribed relations; the "comprehender's" response conforms to the speaker's expectations. Language is viewed by us as a computational activity, the aim of which is to ascertain relations that prevail in given environmental circumstances. Thus it must not be confused with the performance of a fixed action pattern elicited by an acoustic stimulus. In practical terms, this means that a child who waves bye-bye, shows me his nose or how big the baby is, or performs any other fixed trick upon a given oral command has not given evidence of language knowledge. Our brief discussion of the nature of language leads to practical, clinical investigations and language tests of a rather specific kind, more closely related to tests designed to assess mathematical knowledge than tests that are simple inventories of items that are being remembered.

The ontogenetic emergence of language is the result of an interaction between biological (genetic and maturational) factors with social ones. Educators and rehabilitation personnel must acquaint themselves with the relevant biological facts for the intelligent planning and management of practical language problems in health and disease. Table 5 presents a few pointers useful in the diagnosis of clinical language problems, most of them based on observations made in connection with research into the biological foundations of language.

We have also supplied a short survey of recent empirical investigations into language development of normal children. We hope this will aid the assessment of children's progress in both a school and an institutional setting.

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6. SUSTAINED ATTENTION AND IMPULSE CONTROL: IMPLICATIONS FOR THE HANDICAPPED CHILD [1]

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The concept of attention has had an erratic career within the history of psychology. Boring (1970) traces some of the early work on the concept up through the 1920's but points out that it suffered a demise, possibly as the result of the success of positivistic behaviorism, until its rediscovery quite recently. Unfortunately, this neglect has meant that there has been little experimental work on which psychologists within the applied fields could build. This lack is particularly apparent in work with hanicapped children. Although the clinical and educational literature abounds with case descriptions of children suffering from attentional problems, there has been extremely little adequately designed research on these disabilities. As a result, the typical diagnostic evaluation of a handicapped youngster includes no effective, well-standardized techniques to delineate attentional difficulties, and treatment plans often ignore these extremely important symptoms or deal with them in a peripheral and haphazard manner.

Descriptions of attentional problems and problems of impulse control often occur together in clinical reports. This constellation of disabilities has probably been reported most frequently in children diagnosed as brain damaged (Levy, 1959; Ounsted, 1955; Strauss & Lehtinen, 1947). However, the same group of symptoms seems to be prevalent in children falling into the minimal brain dysfunction (Comly, 1955; Millichap & Fowler, 1967; Widrow, 1966), learning disability (Clements, 1966; Dykman, Ackerman, Clements, & Peters, 1971), and hyperactivity (Burks, 1960; Knobel, Wolman & Mason, 1959; Stewart, Pitts, Craig, & Dieruf, 1966) categories. As a matter of fact, these diagnostic labels seem to overlap considerably, quite possibly because problems with attention and impulse control and hyperactivity often occur together and appear as major symptoms in all three disorders. For example, when Clements (1966) listed the 10 most frequently cited characteristics of children with learning disabilities, hyperactivity was first on the list, disorders of attention was fifth, and impulsivity was sixth. Our own work with children diagnosed as hyperactive has convinced us that problems with attention and impulse control permeate and impair their functioning on a wide range of cognitive tasks and in a wide variety of learning and social situations, and we suspect that these difficulties often play an equally important role in the adjustment of the other groups. Recent reports in the literature suggest that problems of attention and impulse control must also be considered as major determinants of the impaired functioning of retarded children (Santostephano & Stayton, 1967; Denny, 1964; Spradlin, Cromwell & Foshee, 1959; Zeaman & House, 1963) and children from disadvantaged homes (Bereiter & Engelman, 1966; Blank & Solomon, 1969; Deutsch, 1964). We are hopeful therefore, that what we learn from our work with hyperactive children will have wider relevance for handicapped children in several other diagnostic categories.

Processes Involved in Attention and Impulse Control

There have been many attempts to define the various aspects of attention. For example, Solley and Murphy (1960) speak of a selective and an integrative aspect. Posner and Boies (1971) postulate three components: alertness, selectivity, and processing capacity. We have found it most helpful to concentrate on what a child must do when he attends, on what demands are made of him. Certainly, all attentive tasks require considerable effort. The individual must remain selectively alert toward certain stimuli or certain kinds of stimuli, often over long periods of time. Sometimes he must maintain this selective alertness in the presence of other, highly compelling stimuli.

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In some instances the stimuli to which he must attend appear sequentially so that they can be processed one by one or in small groups. At other times the individual must actively seek them out in a complex field, and in this case, organized scanning is required. The kinds of stimuli to be processed also make differential demands. Sometimes they have direct, concrete, signal value. For example, they may have relatively obvious physical characteristics as in the case of a simple form. At other times, the individual must be able to discover and react to much more subtle or complex or abstract aspects of the stimulus such as a complex pattern or the functional meaning of the stimulus. Tasks differ, too, in the degree to which the child is left to his own devices. Sometimes there are aids or props which help direct and maintain his attention. The stimuli themselves may be particularly interesting or another individual may warn or remind or encourage him. In other situations, he must generate and maintain a commitment to the task without these aids.

As we have observed children attempting to cope with a variety of these tasks we have been impressed with the amount of self discipline they require. The youngster must often continue to focus on stimuli long after he has lost interest in them. He must also inhibit tendencies to respond to incorrect stimuli, some of which may have considerable attraction for him. Frequently, he must delay responding until he has made a very careful search or considered alternative possibilities in order to be certain of the correctness of his choice. We have concluded that all of these processes require impulse control and we now have a fair amount of empirical data to support this contention. Thus, we have come to consider sustained attention and impulse control as closely related or reciprocal aspects of the same process and we suspect that this is why attentional problems and descriptions of impulsivity occur together so frequently in clinical reports.

Our major research strategy has involved studying the performance of hyperactive and normal children on a wide range of tasks in which the role and importance of attention and impulse control varies: we have also attempted to manipulate various parameters within the tasks and in the testing situation in order to define as carefully as possible the amount and kind of attentive ability which each task demands. We believe that this kind of analysis can lead to a more accurate diagnosis of attentional deficits in particular children and to the establishment of objective criteria for evaluating the effectiveness of treatment and training techniques. We also entertain some hope that careful work of this kind will ultimately shed some light on the etiology of these disorders.

Choice Reaction Time, Serial Reaction, and Vigilance Tasks

Experimental psychologists have developed several laboratory tasks which may prove useful in the assessment of attention and impulse control in children. The work on vigilance has been particularly informative; workers in this field have studied a large number of factors which can influence an individual's efficiency on a vigilance task. These include: time on the task, the probability of occurrence of signals, knowledge of results, the general state of alertness of the subject (including the effect of stimulant drugs), the presence of distracting or competing stimulation, allowing the subject to work at his own speed, the simultaneous use of different senses, and the subject's typical caution or riskiness in reporting stimuli. (Bakan, 1955; Broadbent, 1953; Broadbent, 1964; Baker, 1963; Mackworth, 1964; Mackworth; 1965; Swets, 1964; Tanner & Swets, 1954.) We felt that it would be worthwhile to explore the effects of several of these variables on the performance of hyperactive children and have begun work in this direction.

In one series of studies we focused on the performance of hyperactive and normal children on a choice reaction time task, a serial reaction task and a vigilance task (Sykes, Douglas, & Morgenstern, 1973; Sykes, Douglas, Weiss & Minde, 1971). Trials on the choice reaction time task were discrete, the child was warned before each trial and the stimulus did not appear until the experimenter thought that his attention was directed to the screen. When attention was aided in this way, the hyperactive children were able to choose the correct stimulus and make the appropriate motor response (pushing a lever) as efficiently

as the controls. The serial reaction task consisted of five lights, each associated with an individual push button. As the lights went on, one at a time, the child was required to tap the button corresponding to the light, thus turning it off. As soon as he made his response, another light automatically turned on. Thus, the child worked on his own but he controlled the appearance of the stimuli to which he had to respond. Correct and incorrect responses were scored. A correct response involved pushing the button corresponding to the light on at the time and an incorrect response involved pushing a button when the corresponding light was not on. The hyperactives and normals did not differ significantly on number of correct responses. However, the hyperactive children did push a wrong button significantly more frequently than the normals. Errors of this type may well reflect impulsive responding.

The third task, a continuous performance test, proved to be the measure most sensitive to the attentional problems of these children. This task was experimenter-paced; that is, the stimuli appeared automatically at fixed intervals. There was a visual and an auditory version and the stimuli for both were 12 letters. One letter at a time appeared on a screen or was heard from a voice recorded on tape. In each case, the significant stimulus to which the subject was instructed to respond was the letter X when it was immediately preceded by the letter A. Both the visual and auditory forms of this task revealed differences between the hyperactive and normal children. The two groups differed on both correct and incorrect responses with the hyperactive child making significantly fewer correct and significantly more incorrect responses than the normal controls. Again, the incorrect responses often seem to have resulted from impulsive responding. Observations of these children on this and other tasks suggest that they have difficulty in holding back responses. A particularly obvious example of this was the high incidence of "multiple responses" which involved pushing more than once to the same stimulus. The significant difference in number of correct responses suggests that the performance of hyperactive children is impaired by momentary lapses of attention. On this task, the stimuli appear automatically. Thus, if attention is not focused on the task at the time of their arrival, the subject fails to perceive them. On a subject-paced task, on the other hand, the subject can make up for momentary lapses of attention by working more quickly. This may explain why the hyperactive children were able to achieve as many correct responses as the normal children on the serial reaction task described earlier.

We explored several other parameters that we thought might affect attention on these tasks. On the continuous performance test, scores during the first, second and final 5-minute interval of the task were compared. Duration of time spent at the task clearly heightened the differences between the hyperactive and normal subjects. The performance of the hyperactives deteriorated much more markedly over time, a finding which we have replicated with other tasks.

We also attempted to assess the effect of distraction on two of the tests. On the choice reaction time task there was one series of trials in which the colored background of the stimuli appearing on the screen was discrepant with the color of the background of the target stimuli. This condition, which was meant to introduce distracting or conflicting cues, apparently disrupted the two groups equally. On one series of trials on the continuous performance test, white noise of 80 decibels intensity was intermittently piped into the room at random intervals. Again, this attempt to introduce distraction did not affect the hyperactives more than the normals. These and other findings to be discussed later have made us cautious about treating failures of attention and distractibility as identical problems, as clinicians and teachers almost invariably seem to do. It is important to remember that the serious deficits of the hyperactive group on the continuous performance test occurred when the child was alone, in a sound-deadened room, with an absolute minimum of extraneous stimuli present.

We have experimented, too, with pacing tasks at fast and slow intervals. We thought that it might be easier to maintain alertness and cut down distraction in the hyperactive children by presenting the stimuli at a relatively brisk pace. We have tested this hypothesis by presenting stimuli at fast (1.0 second)

and slow (1.5 second) intervals on the continuous performance task: we have also manipulated intertrial intervals on a concept learning task (Freibergs & Douglas, 1969) and preparatory interval on a delayed reaction time task (Cohen & Douglas, in press). However, the results thus far have been negative or ambiguous.

Delayed Reaction Time Task and the Orienting Response

In another study (Cohen, 1970; Cohen & Douglas, 1972) we investigated the skin conductance component of the orienting response in hyperactive and normal children during the presentation of nonsignal tone stimuli and during a delayed reaction time task in which the children were given a warning signal several seconds prior to the appearance of a reaction signal. Basal levels during a rest period were also recorded. We were interested in the basal and orienting response measures because there have been suggestions in the literature that various kinds of children who exhibit attentional problems and diffculties with impulse control may suffer from abnormal arousal levels and/or deficiencies in characteristics of the orienting response and its habituation. It has been suggested, for example, that hyperactive children and children suffering from minimal brain damage or dysfunction may have abnormally high or low, or erratic central activation levels (Conners, 1971; Laufer, Denhoff, & Solomon, 1957; Satterfield & Dawson, 1971; Stewart, 1970; Werry, Sprague, Weiss, & Minde, 1969). Deficiencies in the orienting response have been reported with retarded children and very young normal children (Luria, 1963) and in children diagnosed as having minimal brain dysfunction (Boydstun, Ackerman, Stevens, Clements, Peters, & Dykman, 1968).

In the case of our hyperactive subjects, we found no differences on the skin conductance measures during resting conditions. During the presentation of nonsignal stimuli, no differences were found so long as the stimuli were delivered through earphones and the child was kept immobile in a reclining chair. It is important to note, however, that deficiencies in the orienting response to nonsignal stimuli may appear when the experimental conditions are less carefully designed to control attention and movement; in an earlier study where the stimuli were presented through a speaker in the room and movement was less controlled we did find differences between the hyperactives and controls (Cohen, 1970). Our clearest differences between hyperactive and normal children emerged when they were required to respond to the increased demands of the delayed reaction time task. The controls exhibited a significant increase in both tonic and phasic orienting response measures while the hyperactives remained relatively unresponsive. Thus the warning signal given at the onset of each reaction time trial apparently was not as effective in alerting the hyperactive children and preparing them to respond to the reaction signal.

Performance on the reaction time task was also deficient in the hyperactive subjects. Compared to the controls, they exhibited slower mean reaction times and a greater amount of variability in reaction speed from trial to trial. As in the continuous performance test, their performance tended to deteriorate more rapidly over time. It is important to note, however, that when the trials on which each subject did best were compared, the hyperactive and normal children were indistinguishable. Thus, their poor mean scores appear to result from the erratic nature of their performance. Extreme variability has also marked the performance of these children on several of our other tasks.

Feedback and reinforcement were introduced during the reaction time task in an attempt to study their effect on performance. The reinforcement was personal. The experimenter observed the child's reaction times and said "good" when he reacted especially quickly. Both hyperactives and controls exhibited a marked improvement in reaction times and a decrease in variability under this condition. Both groups also showed an increase in basal skin conductance. However, hyperactives showed no change in orienting response frequency to the warning signal in spite of the improvement in performance on the task. Controls, on the other hand, exhibited an increase in frequency of these responses. When reinforcement was withdrawn, there was a tendency for the performance of the hyperactives

on the reaction time test to deteriorate more quickly than that of normals. These findings suggest that the reinforcement produced general heightened alertness in both groups but that sensitivity to the specific demands of the task occurred only in the normal children. Thus, it is important to make certain that reinforcement is directed specifically toward helping these children focus on the critical stimuli and specific contingencies in a task situation. When reinforcement is used in a less specific way there is always a danger that it will not produce the desired effect or that it may even be disrupting. In a current study in our laboratory, P. Parry has found that generalized, noncontingent praise can actually produce a decrement in performance. It appears as if the impulsive child becomes more interested in the reinforcing adult than in the task demands.

A side finding during the reinforcement condition has also made us somewhat skeptical about conditioning techniques that emphasize training the child in such behaviors as remaining seated and sitting still (e.g., Allen, Henke, Harris, Baer, & Reynolds, 1969; Doubros & Daniels, 1966; Patterson, 1965). We had been recording irrelevant motor responses during the reaction time task and discovered that when reinforcement was introduced the resulting improvement in performance was accompanied by an *increase* in the frequency and amplitude of these movements. These and other findings to be discussed later, suggest that it may not be wise to focus on hyperactivity as the primary symptom in these children.

Concept Learning on an Automated Teaching Task

The results of a study of the performance of hyperactive and normal children on an automated learning task (Freibergs, 1965; Freibergs & Douglas, 1969) also served to heighten the importance of reinforcement contingencies on the performance of the hyperactive child. The concept learning apparatus and concept formation problems used in the study were developed by Dr. Sonia Osler at Johns Hopkins University (Osler & Fivel, 1961). The machine delivers two pictures at a time. One is the exemplar of a concept such as "flower" or "bird" or a number concept (e.g., "two"), the other is a nonexemplar of the concept. The child is told that if he looks at the pictures carefully he will find that there is something in the pictures, like an idea, which will tell him which one to choose to make the machine deliver a marble as often as possible. It is thus possible to observe, step by step, the child's attempt to solve a new problem. Performance on these tasks was studied under a continuous reinforcement condition in which every correct response was awarded and a 50 percent partial reinforcement condition in which every other correct response was rewarded. Number of errors and number of trials to criterion were used as measures of learning efficiency. In spite of suggestions in the literature that they have conceptual difficulties (Burks, 1960; Clements, & Peters, 1962; Rosenfeld & Bradley, 1948), the hyperactive children had no difficulty solving the concepts under the continuous reinforcement condition. They also showed good task-to-task transfer. We were impressed by the way learning in these children seemed to thrive under this condition. The task was self-paced, the stimuli were colorful and interesting and the child received immediate feedback and reward for correct responses. In the partial reinforcement condition, however, the results were very different. A large number of the hyperactive children failed to reach a solution, even after many trials. There are several possible explanations for the extremely detrimental effect produced by reducing feedback and reinforcement in this way and we are currently trying to trace some of them down.

The Pervasiveness of Attention and Impulsivity

Once our laboratory studies had convinced us of the core position of attention and impulsivity in the hyperkinetic syndrome, we became more aware of the extent to which these factors pervade the performance of hyperactive children on a wide range of cognitive tasks and in a wide range of social situations. Indeed, we have come to feel that knowledge of individual differences in the ability to sustain attention and keep impulsive responding under control is fundamental to an understanding of the intellectual functioning and social adjustment of both normal and handicapped children. Evidence for this contention has come from several somewhat disparate sources.

Cognitive Style. In the past several years, researchers in the field of developmental psychology have become interested in assessing individual differences in the manner in which children approach tasks. These "cognitive styles" are thought to reflect rather consistent preferences for particular problem solving strategies rather than differences in intelligence or cognitive abilities. We have found the cognitive style approach interesting because some of the "styles" that have been delineated place heavy emphasis on such factors as the child's typical manner of exploring or attending to new stimuli and his ability to inhibit impulsive responding and to withstand distraction. Evidence is accumulating that the cognitive styles are related to a large number of cognitive and personality measures. We have studied the performance of hyperactive and normal children on several tests of cognitive style and have also investigated relationships between these measures and other measures of attention and impulse control.

The cognitive styles of reflection-impulsivity (Kagan, Rosman, Day, Albert, & Phillips, 1964) and field dependence-independence (Witkin, Dyk, Faterson, Goodenough, & Karp, 1962) appeared to us to be rather closely related to the problems I have been discussing. Reflection-impulsivity refers to the child's typical conceptual tempo, that is, his tendency to respond slowly or rapidly when confronted with a problem-solving situation in which there is a high degree of uncertainty resulting from the fact that several alternative solutions are possible. Kagan has developed a visual matching task, the Matching Familiar Figures Test, as a measure of reflection-impulsivity. The performance of the reflective child is characterized by long latencies and few errors. The impulsive child, on the other hand tends to respond quickly with little critical evaluation of alternatives; as a result, he makes more errors. Various investigators have demonstrated that impulsivity decreases with age (Kagan et al., 1964) and is not significantly correlated with verbal intelligence (Kagan, 1966). Repucci (1970) reports that as early as 2 years of age, reflective children show more sustained involvement with toys. Impulsivity has been shown to be related to errors of commission on a serial learning task (Kagan, 1966), reading errors (Kagan, 1965) and higher error scores on tests of inductive reasoning (Kagan, Pearson, & Welch, 1966). Kagan et al. (1964) have also found that children scoring high on impulsivity are more distractible, less attentive, more physically active and have poorer motor control than their reflective peers. Finally, reflective children show greater persistence on difficult intellectual tasks (Kagan, 1965) and are more concerned with success on intellectual tasks (Kagan et al., 1966).

Field dependence-independence reflects individual differences in the ability to separate an item from the field in which it is embedded (Witkin, 1959; Witkin et al., 1962). The dimension also refers to the degree to which perception is global or analytic (Witkin et al., 1962). The field independent individual is better able to overcome a confusing, embedded context when isolating figure from ground. Like reflection-impulsivity field dependence decreases with age and is unrelated to verbal intelligence, although it does show moderate correlations with some of the performance subtests on the Wechsler Intelligence tests which involve perceptual-organization (Goodenough & Karp, 1961; Witkin et al., 1962). Children who are field dependent are more likely than field independent children to engage in undirected motor output and to have poor impulse control (Witkin et al., 1962), a description which is in close agreement with Kagan's findings on the impulsive child. Personality descriptions are also similar; the field independent individual is described as being more emotionally independent and self-confident and more concerned with intellectual mastery.

Our belief that these two cognitive styles share common properties that are related to attention and impulse control has been supported in several ways. Both the Matching Familiar Figures Test and the Children's Embedded Figures Test significantly differentiated between hyperactive children and normal controls, with the hyperactives receiving significantly higher field dependence and impulsivity scores (Campbell, Douglas, & Morgenstern, 1971). This finding has been replicated in a followup study with a group of teenage hyperactive children (Cohen, Weiss, & Minde, in press). Within the hyperactive group there were also significant correlations between the

cognitive style measures and scores on the continuous performance test and the delayed reaction time task discussed above (Douglas, 1972).

Similar correlations have also been found within samples of normal children. We administered a battery of tests to normal boys which included several measures previously shown to differentiate between hyperactive and normal children. Besides the two cognitive style tests, these included the continuous performance test; a test measuring ability to discriminate between the loudness of tones; the Porteus Mazes, which are considered a measure of planning ability (Porteus, 1959, 1965); and a teacher-rating scale which we had developed to measure some of the most common symptoms of hyperactivity, including attention span, independence, tolerance for frustration, and amount of body movement. A principal axis factor analysis followed by a varimax rotation was performed on these measures. All of the above variables plus a few to be discussed, loaded significantly on the first factor extracted. It is important to note that neither age nor IQ loaded on this factor. Tests measuring anxiety also emerged as a separate factor (Douglas, 1972; Marton & Douglas, unpublished manuscript).

It is interesting to speculate about how our postulated attention-impulsivity factor may be influencing performance on the two cognitive style tests. The most direct evidence comes from techniques which have been used to record eye movements and scanning behavior while children are taking the Matching Familiar Figures Test. These methods have revealed that reflective children engage in more systematic searching among the alternative pictures and also make more comparison glances between the standard and the various alternatives (Drake, 1970; Siegelman, 1969). Such an approach demands sustained, well-organized attention as well as inhibition of the inclination to settle for a less-than-perfect alternative. It seems likely that similar processes enable the field-independent child to withstand the influence of a confusing context and to differentiate the designs on the Embedded Figures Test into their component parts rather than treating them in a diffuse, global manner (Witkin, 1965).

Some recent reports in the literature demonstrate the extent to which these abilities may influence a child's performance on several different kinds of cognitive tasks. Katz (1971) has shown a relationship between reflection-impulsivity as measured by the Matching Familiar Figures Test and color-form sorting preferences. She explains her results in terms of the impulsive child's tendency not to go beyond the perceptually dominant stimulus attributes of the task. Birch and Bortner (1966) have shown the effect of stimulus competition on category usage in children. They argue that young children may give the appearance of being unable to make functional and class categorical choices because they respond impulsively to the more prepotent characteristics of the task stimuli. Odom, McIntyre, and Neale (1971) have found differences between reflective and impulsive children on perceptual learning tasks; the reflective children showed a greater tendency to perceive and evaluate information based on distinctive feature differences of stimulus arrays.

Learning Disabilities and School Achievement. Early in our work with hyperactive children, we administered an extensive battery of tests designed to tap learning disabilities to matched samples of hyperactive and normal children (Douglas, 1972). We had rather expected to find evidence of learning problems in the hyperactive group because of a substantial proportion of our hyperactive subjects had failed one or more grades in school and a study of their report cards had revealed that they were receiving lower grades than classmate controls on virtually all academic subjects (Minde, Lewin, Weiss, Lavigueur, Douglas, & Sykes, 1971). However, we were somewhat surprised to discover no significant differences between the two groups on the majority of our tests. For example, the hyperactives, as a group, had no more difficulty than the normal children with items measuring short-term memory, language ability, abstract reasoning, or reading ability. It should be remembered, however, that the tests in the battery were individually administered; comparisons with tests which had been group administered in the schools often showed striking differences. We suspect, therefore, that attentional and impulsivity problems

account for a substantial proportion of the academic failures of the hyperactive group. Classroom observations (Douglas, Bradley, Weiss, & Minde, unpublished manuscript; Douglas, 1972) tend to substantiate this. The hyperactive children spent significantly more time than normals on activities that were inappropriate to the ongoing classroom activity. They also indulged in more inappropriate vocalizations and movements around the classroom.

There is one group of tests, however, on which our hyperactive children consistently have done badly. These are tests usually thought of as measuring perceptual motor and fine and gross motor abilities; they include the Bender Visual-Motor Gestalt Test, the Lincoln-Oseretsky Motor Development Schedule, the Eye-Motor Coordination subtest of the Frostig Developmental Test of Visual Perception, the overall score on the Frostig, and the Goodenough-Harris Draw-a-Person Test. Interestingly, two of these tests, the Bender Visual-Motor Gestalt Test and the Eye-Motor Coordination subtest of the Frostig, also loaded significantly on the attention-impulsivity factor in our factor analytic study with normal boys. We have been intrigued by the repeated finding that attentional and perceptual motor deficits seem to occur together. It is tempting to postulate some neurological relationship between the two systems. On the other hand, these tests tap the child's ability to look and move carefully, just as the other tests we have been discussing tap the ability to look and/or listen carefully. Also, to perform well on the Bender-Gestalt Test the child must be able to analyze the figures into their component parts, an operation which is probably similar to the approach required for good performance on the Children's Embedded Figures Test of field dependence. It is perhaps important to add here that the poor performance of the hyperactive children on the Bender-Gestalt Test does not seem to result from carelessness due to poor motivation. We have tried paying them to take extra care but have seen little improvement, even when the children seem to be trying especially hard to reproduce the figures correctly.

Personality Measures. It seemed unlikely that the influence of attention and impulsivity would be limited to the cognitive area. As we have seen, Kagan and Witkin have shown relationships between the cognitive styles and personality measures. We have begun some preliminary studies to discover the extent to which our attentional-impulsivity factor pervades a child's interpersonal relationships and social functioning. In previous research we have found story completion techniques valuable instruments for reflecting the maturity of a child's response to frustration (Douglas, 1963) and aggression (Bildfell & Douglas, 1965). P. Perry has just completed a study using these instruments with young hyperactive boys. She has found that when they are confronted with stories depicting inescapable frustration they are unable to modulate their expectations to accept a compromise solution. They tend, rather, to expect an unrealistically happy outcome. They also give more acting-out, aggressive responses than the normal controls. In order to see whether responses of this kind were related to our postulated attention-impulsivity factor, these same stories were included in the factor analytic study with normal boys described above. As expected, compromise responses showed a significant positive loading on the factor while aggressive responses loaded negatively.

In another series of studies we have been exploring the extent to which attention and impulsivity are related to moral development as described by Piaget (1932). We had been struck by the similarities between the skills required in the tests of reflection-impulsivity and field dependence-independence and Piaget's concepts of "syncretism" and "centration." Syncretism refers to the child's reacting globally to a situation rather than anlyzing its elements; the related concept of centration refers to the child's tendency to focus on some striking but superficial aspect of a phenomenon. Piaget sees these processes as playing an important role in social as well as cognitive development. In the course of moral development, for example, the child gradually learns to be less swayed by the consequences of an act, even when they are dramatic, and to stop to consider the intentions of the actor.

We have used story techniques originally developed by Piaget (1932), and modified by Crowley (1968), as well as specially prepared films, to investigate the relationship between

the two cognitive styles and level of moral development. In one study comparing children with high and low scores on intentionality, the high intentional children received higher scores on field independence and reflectivity on the cognitive style tasks. They were also rated by their teachers as being more reflective, attentive and confident.

In two other studies, significant correlations were found between the cognitive style measures and maturity of moral judgments; all three measures also showed significant negative correlations with teachers' ratings of aggressivity. Again, intelligence test scores did not correlate significantly with the cognitive styles and moral development measures (Schleifer, 1971; Schleifer & Douglas, unpublished manuscript).

We were rather reassured to discover that another group of researchers (Grim, Kohlberg, & White, 1968) have also found significant relationships between attentional measures and moral behavior. Their findings resulted from the chance meeting of two studies being carried out with the same subjects. In one, a reaction time task with associated galvanic skin response measures was being used to study attention. In the other, behavioral measures and teacher ratings of resistance to temptation were used to study cheating behavior. In two different groups of children significant correlations were found between good performance on the attention measures and the ability to resist temptation. The authors cite studies by Flavell and Draguns (1957), Schilder (1951), Werner (1957), and White (1965a, 1965b) which demonstrate that "cognitive operations which further attention to detail, planning and inference are attained in part because the individual is able to resist the impulse toward less sophisticated solutions" (p. 40). Cheating, they believe, also involves inability to resist a quick, effortless solution.

As we have been following our hyperactive children into adolescence, we have discovered that a substantial proportion of them are becoming involved in delinquent acts (Weiss, Minde, Werry, Douglas, & Nemeth, 1971). Stewart (1970) also reports that when his hyperactive children reached teenage they showed "a distinct increase in impatience, resistance to discipline, irritability and lying" (p. 97). Delinquent behavior was also common. It seems likely that the kinds of attentional and impulsivity problems I have been describing contribute to these behaviors.

Effects of Stimulant Drugs

Evidence is rapidly accumulating to support the effectiveness of stimulant drugs in the treatment of children whose major symptoms include poor attention and impulse control. Several investigators have reported generally improved performance on batteries of psychological tests which have contained measures of intelligence, learning, perceptual-motor, and other cognitive abilities (Conners, Eisenberg, & Sharpe, 1964; Douglas, 1971; Knights & Hinton, 1969; Millichap, Aymat, Sturgis, Larsen, & Egan, 1968). However, there does not seem to be any particular pattern of improvement obtained on these fairly gross measures. For example, in some of the above studies, performance scores on the Wechsler Intelligence Scale for Children reach a statistically significant level of improvement, while in our own study it was the verbal score that increased significantly. We suspect that these inconsistencies are due to the fact that attentional factors permeate all of these tests. If the effects of the drugs are mainly on attentional processes, one might expect the rather general but inconsistent pattern of improvement that has been found.

Several of our own studies, as well as those of others, have convinced us that the stimulants do exert their main effect on attention and impulse control. Our typical research design has involved administering the measures of attention and impulsivity to normal and hyperactive children in order to define the specific disabilities of the hyperactive group. We then administer one of the stimulant drugs and a placebo in a double blind, crossover design, to the same hyperactive children. In one series of studies we used methylphenidate, gradually increasing the original dosage of 5 mg/day over a 14-day period to a maximum of 100 mg/day. We found that when the hyperactive children were receiving the drug they made more correct responses and fewer incorrect responses on the continuous performance test (Sykes, 1969; Sykes et al., 1971; Sykes et al., in press). Methylphenidate also improved reaction time

and decreased variability on the delayed reaction time test (Cohen, 1970; Cohen et al., 1971) and produced longer latencies and fewer errors on the Matching Familiar Figures Test of Reflection-Impulsivity (Campbell, 1969; Campbell et al., 1971).

Other investigators have reported similar results. Sprague, Barnes, and Werry (1970) found that methylphenidate significantly enhanced attending behavior in underachieving boys. In a study with hyperactive children, Knights and Hinton (1969) found that methylphenidate improved sustained attention and increased the ability to plan and to rapidly correct errors. Conners and Rothschild (1968) report that dextroamphetamine and methylphenidate improved the performance of children with learning disorders on the continuous performance test. Conners (1971a) also reports several different studies with children with learning disabilities and/or behavior problems, in which he and his associates have found that performance on the Porteus Mazes was enhanced by stimulant drugs. Indeed, Conners and his associates (Conners, Rothschild, Eisenberg, Schwartz, & Robinson, 1969) appear to have reached conclusions very similar to our own when they summed up their experience with the stimulants by suggesting that their major effect was to produce "increased capacity for reflective, inhibited, performance."

The Problem of Diagnosis: Defining the Population

If problems of attention and impulse control do, in fact, play the key role in several children's disorders that has been suggested, it may well be that we can eliminate some of the confusion surrounding these disorders by concentrating our diagnostic and treatment efforts on these symptoms. Hopefully, such an approach may also provide some useful insights on the question of etiology, a topic on which there has been much controversy and speculation but little in the way of definitive answers.

A good deal of the research on these problems has been done with children who have been diagnosed as belonging within the hyperactive, minimal brain dysfunction or learning disability categories. Unfortunately, however, these categories have been loosely defined and there is a great deal of overlap among them. Even when two researchers use the same label, it is impossible to know whether they are, in fact, talking about the same kinds of children. In some studies retarded children have been included in the samples while in others they have not. Some have included children with clear signs or histories of brain damage; others have excluded them. In some samples there seems to be a high proportion of children with serious acting out and delinquent tendencies while in others these problems are relatively infrequent.

Although researchers and clinicians have been expressing discontent with these labels for years (e.g., Birch, 1964; Johnson & Myklebust, 1967; Kirk, 1968; MacKeith, 1962), little progress has been made toward improving diagnostic procedures. Possibly a large-scale study involving large numbers of children from several clinics and a battery of reasonably valid and reliable diagnostic instruments would reveal symptom complexes within these groups. Until this can be accomplished, however, researchers should concentrate on developing as objective measures as possible for defining their samples. When we began our research, we decided to focus on hyperactivity as a target symptom because it seemed less vague and more operationally definable than the constellations of symptoms used in the diagnosis of the minimal brain dysfunction or learning disability groups. Although we still believe this to be true, we are now less satisfied with concentrating on hyperactivity as the critical symtom. Attempts to measure activity level have not always led to clear findings (Cromwell, Baumeister, & Hawkins, 1963). The consensus seems to be that it is the quality rather the the quantity of activity that is important; that is, it is necessary to take into account the extent to which the child's behavior is organized and goal directed and conforms to the demands being made upon him. Certainly, our own studies seem to be pointing to the same conclusion. Our thinking was very much influenced by our followup studies which showed that impaired attention and impulsivity remain serious problems when our subjects reach adolescense, even though hyperactivity had diminished considerably (Weiss et al., 1971). There is also reason to believe that decreased

activity level is not always accompanied by improved concentration and behavior control Millichap & Boldrey, 1967; Sprague, Werry, & Scott, 1969). As I mentioned earlier, this fact became particularly evident during one of our own studies in which praise for good performance led to both improved reaction times and increased extraneous movement (Cohen & Douglas, 1972).

A similar emphasis on attentional and impulsivity problems seems to be emerging from the work of other investigators. I have already mentioned that Conners et al. (1969) believe that the stimulants exert their main effects on the child's ability to reflect and inhibit impulsive responding. Recently, Dykman et al. (1971) published a paper entitled "Specific learning disabilities: An attentional deficit syndrome." In it they reviewed two of their own rather comprehensive studies, one with a group of children diagnosed as suffering from minimal brain dysfunction and the other with a learning disability group. They conclude that the cardinal symptom in these children is defective attention; it is important to note, as well, that they also found evidence of impulsivity in their subjects.

All of these findings suggest that it may be worth considering an approach in which the existing diagnostic labels are ignored and subjects are chosen instead on the basis of attentional problems and poor impulse control. In order to accomplish this, it will be necessary to establish as objective criteria as possible for making this selection. One could start out by choosing children where these symptoms clearly stand out among the initial complaints made by parents and teachers. It would then be necessary to confirm the seriousness of the symptoms. Rating scales could be used for an initial screening, but ultimately, it will be necessary to develop a battery of well-standardized, valid, and reliable measures. This will require a good deal of effort; however, several techniques show promise. Among the tests used in our own studies, I would favor ones which have differentiated between hyperactive and normal children and which have also shown significant changes with stimulant drug treatment. This would include the continuous performance test, the delayed reaction time task and the Matching Familiar Figure Test of Reflection-Impulsivity. The Matching Familiar Figures Test makes an interesting addition because, unlike the reaction time task, it requires slow reaction times for good performance. The Porteus Maze Test should probably be included since we have found clear deficits on this test among our hyperactives and several studies have shown it to be sensitive to the stimulant drugs. We are also experimenting at the present time with the Wisconsin Card Sorting Test (Grant & Berg, 1948) because Milner (1963, 1964) has reported that both this test and maze-type tests were sensitive to the inability of patients who has sustained frontal lesions to follow rules and to use speech to guide their own behavior. Until we learn more about the apparent link between some of the perceptual-motor measures and attentional problems, it would be interesting to include the Bender Visual-Motor Gestalt Test and possibly one or two other motor or visual-motor tests. In order to sample from the auditory modality, along with the auditory version of the continuous performance test, it might be helpful to include tone or loudness discrimination tests. In our work, we have simply used some of the subtests of the Seashore Test of Musical Ability (Seashore, Lewis, & Saetveit, 1956). However, Dykman et al. (1971) have developed a more sophisticated tone discrimination task. These same authors have used a conditioning and impulsivity test originally devised by Brown, Bilodeau, and Baron (1951) which is worth consideration. Another technique which looks promising is a recognition task described by Sternberg (1966) and used with children with attentional problems by Sprague et al. (1970).

Almost all of the aforementioned measures will require a good deal of development and standardization before they can be used as diagnostic instruments. However, if this could be accomplished, we would finally be in the position of having a standardized battery which could be used for both diagnostic purposes and for evaluating the effectiveness of different approaches to training and treatment. Although I have been stressing the minimal brain dysfunction, learning disability, and hyperactive groups, such a battery would have wide applicability to all handicapped children in which attentional problems and poor impulse

control are interfering with learning and adjustment.

Speculations About Etiology

It is possible that a more empirical approach to diagnosis like the one suggested might reduce some of the confusion that exists around the question of etiology of the disorders we have been discussing. Although there is some recognition that severe environmental deprivation can contribute to some of these symptoms (Bereiter & Engelman, 1966; Deutsch, 1964), by far the largest proportion of theorists who have discussed hyperactivity, learning disabilities, and minimal brain dysfunction have preferred physiological explanations.

The physiologizing has taken many forms. Some investigators have pointed to the generally immature behavior of these children and have postulated some sort of "lag" in central nervous system development (Lucas, Rodin, & Simson, 1965; Lytton & Knobel, 1958; Solomons, 1965). Most of the theorists taking this position seem to have assumed that the children will ultimately "catch up" with their peers. However, we must question whether this hypothesis continues to be tenable as more data accumulate to suggest that many of these youngsters do not outgrow their symptoms.

The most popular explanation for these disabilities has involved some kind of brain damage; most frequently birth injuries have been suspected (Gross & Wilson, 1964; Laufer & Denhoff, 1957; Levy, 1959; Martin, 1967; Rosenfeld & Bradley, 1948). Indeed, the label "minimal brain damage" and the later, more ambiguous term "minimal brain dysfunction" were introduced because of similarities between these children's symptoms and those shown by children with established brain damage (MacKeith, 1962; McCarthy & McCarthy, 1970; Stevens, Boystun, Dykman, Peters, & Sinton, 1967; Strauss & Lehtinen, 1947). The debate over the presence of "organic signs" or of a history of factors that might have caused brain damage is still being waged (Gross & Wilson, 1964; Laufer & Denhoff, 1957; Levy, 1959; MacKeith, 1962; Martin, 1967; Rosenfeld & Bradley, 1948; Stevens et al., 1967). Unfortunately, however, diagnostic and methodological problems have made it almost impossible to reach any firm conclusions. Most of the studies reporting the presence of "soft" neurological signs or abnormal electroencephalograms have failed to submit a control group to the same careful search for neurological abnormalities. Some studies, too, have included retarded children and children with clear neurological symptoms in their samples while others, like our own, have excluded them in order to discover whether the more subtle signs are present in children where the picture is not confused by such disorders as cerebral palsy and retardation. Thus far, members of our team have failed to find substantial evidence of brain damage in our children's birth histories, electroencephalograms, or neurological examinations (Minde, Webb, & Sykes, 1968; Werry, Weiss, Dogan, Minde, & Douglas, 1969; Werry, Weiss, & Douglas, 1964), although like the psychological tests, the neurological examinations have shown the children to be physically uncoordinated.

There has been a good deal of theorizing about the nature of the brain mechanisms underlying these disorders. Among the possibilities that have been mentioned are the failure of some essential inhibitory control or filtering mechanism (Laufer et al., 1957) and an imbalance between cortical and subcortical structures which results in the cortex having insufficient control over subcortical centres (Knobel et al., 1959). The reticular activating system plays an important role in several of these theories. Many of the theorists also think of the hyperactive child as suffering from either an abnormally high or an abnormally low level of physiological arousal (Laufer et al., 1957; Satterfield & Dawson, 1971; Stewart, 1970; Werry et al., 1969). Reasoning for these beliefs is based on the children's high level of behavioral activity, the fact that they appear to be searching for sensory and kinesthetic input and the effect of the stimulant drugs. The notion of "physiological arousal" is a highly complex one; however, there is some evidence which may have some bearing on this issue. It will be recalled that in our own studies (Cohen & Douglas, 1972) we found no significant differences between resting levels of hyperactives and normals on either skin conductance or heart rate measures. Differences between the two groups showed up only on orienting response measures when the

children were required to attend and respond to stimuli. However, this matter is far from settled. Although the findings of other investigators (Boydstun et al., 1968; Stevens, Boydstun, Ackerman, & Dykman, 1968) have tended to agree with our results, Satterfield and Dawson (1971) reported abnormally low arousal levels in their hyperactive group. To complicate matters further, more recently, Satterfield (personal communication) has found abnormally high levels. Satterfield has suggested that these conflicting findings may be the result of differences in laboratory conditions in the two studies. We, also, have found physiological recordings in these children to be unusually sensitive to relatively minor changes in methodology. This may be due to the attentional problems I have been describing and also, perhaps, to a high degree of lability in both their behavioral and physiological responsivity. Certainly studies which we currently have underway have shown them to be unusually reactive to both praise and failure.

Recently, several authors have become interested in the possibility that these children suffer from some sort of biochemical defect (Shetty, 1971; Silver, 1971; Stewart, 1970). Norepinephrine is the chemical most frequently mentioned, partly because its release is thought to be stimulated by the amphetamines (Carr & Moore, 1969; Stein & Wise, 1969). Several of the investigators who have adopted a biochemical explanation believe that hyperactivity is a hereditary trait (Silver, 1971; Stewart, 1970). The fact that hyperactivity is so much more common in males than in females suggests the possibility that it is a sex-linked or sex-influenced character; however, males are also thought to be more vulnerable to brain injuries.

Clearly, these disorders present a real challenge to the physiological psychologist. It may be that some of the newer and more sophisticated psychophysiological techniques such as evoked potentials or contingent negative variation (Conners, 1971b) will provide more fruitful clues; or perhaps ways will be found to explore the biochemical differences that have been hypothesized. Certainly, however, the first step should involve developing more objective diagnostic methods. Once satisfactory methods have been established for diagnosing these disabilities and evaluating the effects of treatment, it might be interesting to undertake a detailed study of a group of children whose symptoms have been shown to respond well to the stimulant drug.

Training Techniques

When we consider the debilitating effects and the pervasiveness of impaired attention and impulsivity problems in children, it is discouraging to discover that relatively little effort has gone into developing training techniques to combat these disabilities. The advent of the stimulant drugs has probably contributed to this neglect. It must be remembered, however, that up until the present time, there are no well-designed studies of the long-term effect of the stimulants. Furthermore, the discouraging results of followup studies with children who demonstrate these symptoms offer little hope that the drugs can be used simply as a "holding action" for a few years until the child outgrows his problems. It is conceivable, of course, that we will discover that children can be kept on the drugs safely and effectively throughout childhood and adolescence, and even adulthood. However, it would be foolhardy to count on the drugs completely. There is now sufficient evidence to offer some hope that it may be possible to develop training and teaching methods which can help overcome or at least alleviate these difficulties. It is also possible that drug treatment, in conjunction with training, will increase our chances of success.

Some studies have used positive reinforcement to condition such behaviors as sitting still and looking at the teacher (e.g., Allen et al., 1969; Doubros & Daniels, 1966; Pihl, 1967). These and other studies that emphasize reducing activity level rest on an explicit or implicit assumption that hyperactive behavior is a critical and causative factor in the child's psychopathology and impaired ability to learn. Reasonable arguments for this causative relationship have been advanced by some authors (Dykman et al., 1971; Keogh, 1971; Sprague & Toppe, 1966). On the other hand, I have presented evidence which had made us question whether hyperactivity plays such a focal role. Certainly the success of techniques which emphasize reducing excessive activity should furnish important data on this issue. However,

although these techniques have sometimes been successful in reducing activity level, there is little evidence thus far that this improvement persists after reinforcement is withdrawn (Quay, Sprague, Werry, & McQueen, 1966). More important, there is no proof that a reduction in activity level is accompanied by improved learning.

Another approach has emphasized eliminating distracting stimuli from the child's learning environment. A popular method developed by Strauss and Lehtinen (1947) in their work with brain-injured children has involved placing the children in cubicles while they are studying or being taught. Unfortunately, several studies using these methods have produced disappointing results (Cruikshank, Bantzen, Ratzeberg, & Tannehauser, 1961; Haring & Phillips, 1962; Rost & Charles, 1967; Shores & Haubrich, 1969). Investigators who have adopted this approach have assumed, of course, that their subjects are highly distractible. As I mentioned earlier, our own attempts to introduce distracting and competing stimuli while our hyperactive children were performing on the continuous performance test and the choice reaction time task forced us to question this assumption. Further work, using distracting and competing stimuli with the Color Distraction Test developed by Santostefano and Paley (1964) and the Stroop Color-Word Interference Test (Stroop, 1935) has also produced negative results (Campbell et al., 1971; Cohen et al., in press). Whitman and Sprague (1968) report similar findings with a group of retarded children. They introduced highly engaging stimuli such as balloons, toy soldiers, and candy as well as taped recordings of folk songs while the children were working on discrimination problems. There was no evidence that this condition impaired the performance of the retarded subjects; in fact, there was a tendency for the retarded group to perform more effectively in the presence of the "distractors." In their review of the relevant literature, Whitman and Sprague mention that Brown (1964), Ellis, Hawkins, Preyer, and Jones (1963), Girardeau and Ellis (1964), and Schlanger (1958) also report results that are negative or in the unexpected direction. On the other hand, Dykman et al. (1971) apparently did find that random blasts from a very loud "hooter" interfered with the performance of children with learning disabilities on a conditioning task. Obviously, we need to learn a great deal more about what kinds of distracting stimuli affect what kinds of children and on what kinds of tasks these affects occur.

Certainly, our own findings and those of others should make us cautious about assuming that children who have attentional problems are also highly and generally distractible. I would like to go further and suggest that we should keep our minds open to the possibility that the presence of stimulation and/or hyperactive behavior may sometimes help maintain alertness and thus improve attention in some children. As I mentioned earlier, a similar possibility has been suggested by Satterfield and Dawson (1971). Dykman et al. (1971) have also argued that if all sources of distraction were removed from the environment of children with learning disabilities, restless activity might very well increase. In support of this argument they cite a study by Cromwell et al. (1963) who found that visual and tactile stimuli decreased the motor activity of hyperactive mental retardates and another by Scott (1970) who used background music to decrease activity in a group of hyperactive subjects.

Fortunately, the available evidence regarding the effect of various learning conditions and training methods on attentional problems is somewhat more clear. Our own work (Cohen & Douglas, 1972; Freibergs & Douglas, 1969; Sykes et al., in press) provides a few clues about methods that may help combat these difficulties. It seems possible, for example, to compensate for lapses in attention by providing learning tasks in which the child has some control over the pacing of the material to be learned. This method has the advantage of keeping the material in front of him until he directs his attention to it. Performance can be improved, too, by making special efforts to engage the child's attention and by using techniques which encourage him to focus on the critical aspects of a problem selection.

Our data suggest that these children will respond better if the task to be learned is broken into parts and if the teacher helps reorient the child before each part is introduced. Their attention seems to be improved, too, when the stimuli to be learned are particularly

attractive and colorful, when the children are required to make an active response to each problem, and when they are consistently reinforced with either personal or material rewards.

The studies utilizing reinforcement suggest that our hyperactive subjects are particularly dependent on external reinforcement and/or feedback. It will be recalled that they coped well with concept learning tasks when continuous reinforcement was provided, whereas they had considerable difficulty under the partial reinforcement condition. They also responded well to praise on the delayed reaction time task but their performance deteriorated quickly when reinforcement was withdrawn. Other investigators have also discussed this problem (Patterson, 1965; Patterson, Jones, Whittier, & Wright, 1965; Quay, Sprague, Werry, & McQueen, 1966). As a result of these findings, we have been attempting to learn more about how reinforcement affects the performance of these children. We currently have studies underway in which we are investigating the influence of reward on both motivation and attention. We are also investigating the effect of contingent vs. noncontingent reinforcement: preliminary results underline the importance of tying reinforcement specifically to the aspects of a task which are to be learned. The data suggest that when these children receive generalized, noncontingent reinforcement they became overly excited and focus on the reinforcement rather than the task. If these children, do, in fact, depend too heavily on external reward and feedback, then it becomes desirable to find ways of reducing this dependency. It might be possible for example, to train them to expect and accept a gradually reduced reinforcement schedule. The possibility of teaching them to reinforce themselves is also highly challenging and I shall return to this topic shortly.

Some of our recent data also suggest that experiences of failure are extremely disrupting to these children. Zeaman and House (1963) have provided clear evidence of the effect of failure on a group of retarded children. They found that subjects who had experienced prolonged failure on difficult discrimination problems were unable to learn simple problems which had previously been well within their capacities. As Estes (1970) points out, this experience might be expected to lead to the extinction of attentional responses. One of the most effective ways of avoiding failure is to devise tasks which have been carefully programed from simple to difficult. However, it would be desirable, as well, to teach these children effective methods for coping with the failures that they will inevitably experience.

Most of the approaches that I have discussed thus far place the onus for improvement in the child's performance on the teacher and the learning situation: it would be far preferable to teach the child tactics for overcoming his own deficiencies. A few investigators have concentrated their attention on the ineffective problem solving strategies of these children and have attempted to devise methods to teach them such skills as scanning a task carefully, slowing down before responding, planning a rational approach and reacting unemotionally to failure. Santostefano and Stayton (1967) were impressed by the heavy emphasis placed by Zeaman and House (1963) on the inability of retardates to observe the relevant dimensions of stimuli. In an attempt to correct this deficiency they taught a group of young retarded children to direct their attention selectively and actively by guiding them to choose and pull particular cutouts from a magnetized board. The difficulty level of the choices progressed from simple to complex, thus gradually encouraging the youngsters to direct their attention over the stimulus field and become aware of the properties of the objects displayed. Palkes, Stewart, and Kahana (1968) have shown that training hyperactive boys to use self-directed verbal commands, such as to stop and look before starting a task, and to think before responding, resulted in significant improvement in performance on the Porteus Maze Test. Meichenbaum and Goodman (1971) developed a similar approach, based on Vygotsky's (1962) theorizing about the central role played by internalization of verbal commands in the voluntary control of behavior. They cite several studies including those of Luria (1961), Lovaas (1964), and Meichenbaum and Goodman (1969) which suggest that, as the child matures, there is a progression from external to internal control which is aided by self-guiding, private speech. They successfully used

modeling techniques to teach impulsive children to verbalize and use such strategies as planning ahead, stopping to think, being careful, and correcting errors calmly; self-verbalizations also served a self-rewarding function. It is interesting to note that a similar approach has been considered by Dykman et al. (1971). They suggest that a valuable line of investigation would involve showing that "inner-speech training decreases impulsivity, reaction time or distractibility or increases physiological reactivity" (p. 88).

Other studies are beginning to appear which may help us sharpen our techniques for achieving these goals. Ridberg, Parke, and Hetherington (1971) have influenced impulsivity scores on the Matching Familiar Figures Test by using film mediated models who verbalized and/or demonstrated careful scanning strategies. Siegelman (1969) and Drake (1970) have compared the actual observing behavior of reflective and impulsive children; such studies should provide valuable clues as to what kinds of strategies the impulsive child needs to be taught.

Although most of the studies mentioned thus far have used fairly formal cognitive tasks in their training programs, there is no reason why these methods cannot be adapted to include several other aspects of functioning. We have been experimenting with card games and simple construction projects in which the child can do well only if he proceeds with care and planning. We have also used training techniques to influence social behavior. Following up our finding that children's ability to make mature moral judgments is related to their impulsivity and ability to attend, we have concentrated on teaching children with low moral maturity scores ways of stopping to think and reflect about social events (Schleifer, 1971; Schleifer & Douglas, unpublished manuscript). We have found that it is possible, for example, to teach them to make more considered judgments about another person's actions by training them to stop and take the other individual's intentions into account. Other investigators have also demonstrated the success of similar techniques (e.g., Bandura & McDonald, 1963; Crowley, 1968).

Hopefully, within the next few years we will see the development of imaginative new programs for all types of handicapped youngsters who are unable to sustain attention and keep impulsive responding under control. Treatment, necessarily will begin with sound diagnosis, followed by a choice or combination of several therapeutic approaches. Along with drug therapy, these should include well-researched training techniques designed to help the child cope more effectively, not only with school-like tasks, but also with the wide range of social situations in which his disabilities lead to failure and alienation.

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7. PERSONALITY AND SOCIAL DEVELOPMENT OF HANDICAPPED CHILDREN

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Psychologists' and educators' conception of handicapped children has changed markedly in the last decade. At one time the study of exceptional children was neatly subdivided into discussions of the blind, the deaf, the mentally retarded, the physically handicapped, the gifted and the emotionally disturbed. The present viewpoint is different. For one thing the recognition that so many handicapped children are in fact multiply handicapped has tended to individualize the study of the handicapped child. Each child is a unique person with his own spectrum of handicaps and his own problems in coping with the demands of the world. For another thing, we have come to recognize that many of the problems faced by handicapped people are not strikingly different for people with different handicaps. The prejudices they face and the sympathy they receive are not fundamentally different whether the person is blind or walks with the aid of braces and crutches. Furthermore, the reactions of a blind child to being overprotected by his mother, if that is her response to his blindness, is not vastly different from the reactions of any child in an overprotective home. Thus the whole array of physical handicaps, emotional disturbances and normal adjustments are seen merging imperceptibly into one another while each child is viewed as an individual coping with his individual problems.

The traditional view of compartmentalized disturbances and handicaps probably reflected the influence of the medical model of disease which lead to such tremendous accomplishments in the development of diagnosis and treatment of disease, but which is gradually being replaced even in physical medicine by a more interactive point of view. Medicine traditionally considered disease to be a disease of the individual which reflected some malfunctioning of his body. One task for medicine was to develop diagnostic procedures for testing the individual for disease. A second was the development of therapies for treating disease and immunizations for making the individual resistant to disease. Guided by this conception, medicine developed a tremendous armamentarium of clinical tests and a materia medica of agents for treating disease which have conquered many once terrifying diseases like pneumonia and poliomyelitis.

It was only reasonable that the same strategy would be employed in the attempt to understand and control psychological disturbances and the strategy was by no means fruitless. Various psychological syndromes have been described and psychological tests developed to help diagnose mental illness, but the effort was never as successful as it had been in physical medicine. Goldfarb (1970) in a recent review of psychosis in children concludes with an assessment of current diagnostic procedures:

> This review of current progress in etiological understanding of childhood psychosis emphasizes that the primary requirement for scientific investigation and evaluative research is a meaningful subclassification of children who are presently included in the broad class of psychotic children (p. 818).

Modern medicine, without renouncing the value of syndromes and individual therapy has faced problems which require a much more interactive viewpoint in which the individual characteristics and the environmental hazards are seen as both contributing to malfunctioning of the organism and the methods for achieving control may be focused on the individual or the environment or both. Allergies involve the interaction of a susceptible or vulnerable organism and the presence of the appropriate allergen. To control one allergy we spray parks to get rid of poison ivy and try to inoculate people who are especially susceptible to it. Other diseases are thought of as caused by an agent constantly present in the body, but leading to overt illness only at times when the person has a lower resistance than normal. Some symptoms, like fever and a high white

blood cell count, are part of the organism's coping with infection and are common in all infections; other symptoms are indications of the disease itself.

It seems as if in the realm of psychological disturbances, these complicated interactions between the individual and his environment are very common, but well defined syndromes whose identification leads to effective treatment are relatively rare. They do exist; Wender (1971) for example argues strongly for a minimun brain-damage MBD syndrome whose specific treatment is amphetamine. But generally speaking, psychological problems involve a vulnerable organism interacting with a sort of "allergenic" environment which leads to a deterioration of interpersonal relations. On top of this etiological interaction, the presence of a handicap or an overt psychological disturbance creates social reactions which often are more difficult to cope with than the handicap itself. These social responses to handicaps and their effects on the individual constitute the subject matter of somatopsychology (Wright 1960).

This broadening of the perspective on the exceptional child opens the way for meaningful research by social scientists. Handicapped children have often been viewed from the point of view of treatment of their special problem, and thus of interest primarily to the investigator in special education or physical therapy. Now individuals with handicaps can be viewed as adaptive organisms within an environment. Their problems and coping mechanisms can be investigated by the methods of social science. Not only will these methods be helpful in understanding exceptional children, but helpful to social sciences as well because the special problems of the handicapped child may be natural experiments with important theoretical relevance to social psychology.

In this chapter we will be concerned with the personality and social development of children with physical handicaps, intellectual difficulties or social and emotional disturbances.

Relation of Pathological Social Interactions to Handicap

We will argue that a very promising research strategy is the direct observation of the child interacting with the significant people in his environment, and we will discuss in a later section the problems involved in such observational studies and how various investigators have coped with them. First, however, we should recognize that the child's pattern of social interaction may be related to his handicap in various ways.

In some cases the pattern of social interaction is the disturbance itself. Hyperactivity, fidgetiness, and short attention span are part of the MBD syndrome. Autism is itself a behavior pattern. The careful description of the child's social interaction, like Bleuler's naturalistic observations in mental hospitals (1911) is important for the discovery, identification, and labeling of behavior syndromes.

In some cases the social interaction of the child is best described as the reactions of other people to his handicap. It is a consequence rather than a cause of the primary problem. Some people adopt this position in an extreme form, saying essentially that the disease is only society's label and is a disease only by definition. They argue that all psychopathology is nothing more than idiosyncrasy, that the forms of thought called disordered by psychiatry are merely unusual, certainly not more disordered than conventional forms of thinking and possibly much healthier. The label "sick" that is assigned to such psychoses or disturbances is an expression of conventional society's discomfort with such untrammelled thinking.

Taken in this extreme form, the viewpoint is certainly incorrect. Certainly there are individuals, most strikingly the profoundly retarded, who could not function in any society effectively and would have to be taken care of—or disposed of—as in some cultures. Similarly there are psychoses which are completely incapacitating and other forms of psychopathology that are very distressing to the individual and may lead to suicide. But in a milder form this point of view has strong support. Laing (1967) believes that schizophrenic episodes, while necessitating the care of the patient, are struggles for health and are symptoms of adaptive mechanisms, not symptoms of disease, and in many cases the disease itself is less in the patient than in the environment that imposed it on him.

When we move from adult psychosis to childhood disturbances, it becomes even more diffi-

cult to label the patient "sick" and to identify just what symptoms describe his illness. Kanner (1960) for example has said that it is not so much the symptoms themselves as their annoyance value to the family of a child that determine whether he is referred to a clinic. Shepherd, Oppenheim, and Mitchell (1966) found that clinic and nonclinic children did not differ much in the prevalence of symptoms of childhood disorders like fears, tantrums, hyperactivity, etc. What did differentiate the clinic from the nonclinic population was the amount of anxiety such behavior generated in the mother.

One recent attempt to establish the importance of social expectations in the development of the child has been Rosenthal and Jacobson's study, *Pygmalion in the Classroom* (1968). Rosenthal gave teachers false information about some of the students in their classes. These students were reported to have revealed unusual potentiality for intellectual growth in an examination given by the experimenters. The children, thus singled out, were in fact merely a random selection from the class, but sure enough by the end of the year these children had fulfilled the prophecy made for them in the fall. The only basis for such growth seems to have been some consequence of telling the teacher that the children showed promise. An additional study of this sort (Rothbart et al., 1971) used teacher trainees as the instructors in an experimental situation. They were also told that two of the students had more academic potential than the other two. The teachers paid more attention to the high expectation students and those students talked more as a consequence.

Rosenthal and Jacobson's experiment has been severely criticized, largely on methodological grounds. Thorndike (1968) points to the near impossibility of some of the reported test scores, both pretest and posttest. He does not quarrel with the conclusion except to say that Rosenthal's data provide no evidence for it.

Despite these criticisms, there is good reason to think that the basic hypothesis is true. After all, Rosenthal exerted only a mild influence on the teachers by comparison with what happens in ordinary circumstances where a child's record is available to the teacher, where he may have been the subject of discussion between his old and new teacher, and in serious cases where he has a firm reputation that precedes his actual appearance in a class. In such circumstances a diagnosis of "mental retardation" or "minimal brain damage" or "autistic" must exert a powerful influence upon the teacher's handling of the child. If the diagnosis is accurate this influence may be beneficial. The teacher may make allowances and put less pressure on the child and this may be just what he needs. On the other hand if the label is premature—and from what we know about changes in IQ over time and the fallability of soft neurological signs it must be premature in a fair percentage of cases—then it may really hamper the child's learning. If a child is mongoloid, then his physical appearance itself may label him. While many mongoloid children do seem to be seriously retarded, the fact that some of them do develop into the normal range of intelligence (Hunt, 1967; Seagoe, 1964) suggests that some others who might have done so were hampered by the common conception of the mongoloid as a hopelessly retarded individual.

The pattern of social interaction of the handicapped child with his environment may, then, be primarily the reaction of other people to the handicap and may reflect little about his own characteristics. In most cases, however, the pattern of social interaction is the end result of a history of interaction, in which the child's own characteristics have been influential and in which the pattern of handling by his family has also been very important.

Thomas, Chess, and Birch present this viewpoint very cogently and can support it with empirical data (1968). This research team followed the development of 128 children from birth, paying particular attention to the development of behavioral disorders. Through careful interviewing of the mother they rated each child on nine temperamental variables which combined into three major clusters or syndromes. The babies in one group were "easy babies," adaptable, happy and predictable. A second group is labeled "slow to warm up." A third group was labeled "difficult" because the babies found it hard to adjust to schedules and changes in schedule, they fussed a lot, had intense feelings and did not apparently enjoy people. These children were the

most likely to develop behavior disorders requiring psychiatric referral, and the deviant behavior antedated the development of actual symptomatology of disorder. But not all difficult children developed disorders, nor were all the disorders from this group. The important additional factor was the parental reaction. Even a very difficult child might develop normally if the parent was able to be warm yet firm, patient, and consistent, while easy babies might develop disorders if the interaction with the parents took an unfortunate turn. Meyers and Goldfarb (1961) report data that are consistent with this interactive hypothesis. Psychotic children who showed clear signs of brain damage had, on the average, parents who were less disturbed than psychotic children who did not show any evidence for organicity. In other words brain damage may predispose the child to develop a psychosis, even when the parental behavior is normal, but in the absence of such a predisposition a more seriously malfunctioning parent-child relationship is required for the development of psychosis.

Such findings as these point clearly to the importance of describing the parent-child interaction in more detail. The term *difficult* is a general summary of the child's early behavior, but of course what makes a child difficult for one parent does not make him difficult for another.

In the Thomas, Chess, and Birch study, the "difficult" child was temperamentally deviant and the behavior disorder could be seen as an outcome of the early predisposition. Children who are physically handicapped may also be difficult burdens on the parent even in the absence of any temperamental irritability or unadaptiveness. Thus, such children are vulnerable to the development of behavior difficulties that are quite unrelated to the handicap. An auditory defect may make the child so difficult to communicate with that the mother ends up shouting in the child's face and dominating him so unmercifully that he adapts by "turning her off" and thus puts still another barrier between himself and his environment. This sort of vicious circle of interaction is common in the development of behavior disorders.

Since all handicaps create problems for the child's family as well as for himself, the resultant interaction patterns may be similar for different handicaps and different for similar handicaps if the quality of the interaction reflects the pattern of social adaptation more than it does the original handicap. On the other hand investigation might well show that a particular handicap creates a particular kind of burden which some families find especially difficult and thus predispose the child to the development of a particular disorder. Careful study of the mother-infant interactions of children with different handicaps might thus specify the potential problem more explicitly and point to the possibilities of special preventive measures.

In later sections research issues relevant to each of these points of view will be discussed, but they all depend upon the description and analysis of social interaction. The following section is, therefore, a digression of sorts; it will discuss the general problems of describing social interaction, and some of the methods that have been developed in social psychology and sociology for investigating the problem.

The Study of Social Interaction in Naturalistic Situations

In view of the fact that the primary task of social psychology is to understand and explain the social behavior of the individual and since social behavior is in fact social interaction between people, one might think that there would be many investigations of the actual interaction of people in various kinds of situations that typify the social interactions of everyday life. As a matter of fact, however, the bulk of social psychological research has been the study of the statistical relationships between *distant* variables like warmth of the home and conscience development (e.g., Sears, Maccoby, and Levin, 1957), social class and mental disease (e.g., Hollingshead and Redlich, 1958; Kohn, 1968). These are called distant variables because their relationship must be mediated by chains of intermediate events. Poverty does not directly cause mental disease, its positive correlation must depend on what goes on in poor families, perhaps malnutrition, lack of good prenatal care, frustrations built up over being unable to get one's share of life's rewards (see Freedman, 1962), or perhaps certain patterns of child rearing that are common

in poor families (e.g., Radin and Kamii, 1965 and 1967).

While the establishment of the fact that members of poor families are more vulnerable to schizophrenia than people in middle and upper socioeconomic status is important, such a finding really only poses a problem rather than answering it. The answer must partly depend upon the actual study of the events in the lives of poor families, what they eat, how children are treated, what medical care they get, and how family members interact with each other.

Some recent research shows how such studies may change the picture. The fact that lower economic level Negro children have on the average lower IQ test scores than white middle-class children is well established. This is a relationship between distant variables. Without adequate evidence, some social scientists began to describe the Negro ghetto home as disordered and disorganized, in which mother-child interaction is impoverished, and so seriously lacking language resources that children could not talk in complete sentences by the time they entered school. No wonder they failed so badly in school. The facts of low IQ test scores and school failure are undeniable, but the remainder of the picture which fills in many hypothetical mediating factors to connect the distant variables has been shown to be wrong. The Baldwins (1970) recorded and described mother-child interaction for a sample of families born in west Harlem and of white upper middle-class, largely academic families. The actual observation of mother-child interaction was very revealing. While there are some quantitative differences between the two samples, they do not confirm any of the hypothetical descriptions. Mother-child interaction was not less frequent or intense in the Harlem mother-child pairs, the mother's language resources as evidenced in an interview were the same as those of the white mothers. While the language used by mother and child in playing together was somewhat less complex in the Harlem sample, it was not dramatically different. The whole picture of the Harlem family interaction is changed and put into perspective when it is actually observed even if there are statistically significant differences between Negro ghetto homes and white middle-class homes.

Such facts as these make it essential to study social interactions directly in naturalistic situations and make it surprising that such direct studies are not common. It is not as if these social interactions are unobservable. The causal chain that connects trisomy of chromosome 21 with mental deficiency in mongoloid children (Lejeune, Gautier, and Turpin, 1959) requires the development of elaborate biochemical methods, but social interactions are not hidden in the synapses between neurones; they occur out in the open where they can, in principle, be directly observed.

The importance of naturalistic studies and the fact that they have not been frequent, particularly in studies of exceptional children, make it worthwhile to devote some space to a discussion of the methodology of such studies.

The process of observing social interactions in naturalistic situations can be conveniently divided into three steps. The first is the obtaining of a record of the interactions; the second is the coding of the events of this record in terms of the variables that are under investigation; and, finally, the analysis and summary of the interaction in terms of these variables. When this process has been completed for a sample of units, be they individuals, mother-child pairs, families, small groups, or whatever, the usual statistical methods are available for testing the relevant differences, or relationships.

The record may be an audio or video tape of the interactions or the recording and coding may be consolidated so that the observations result in a more or less completely coded record. In some studies the observer uses a predetermined coding system so that the only record of the interaction is a set of codings. Bales' coding of interactions follows this strategy (1950). Bell has developed a check list for the observation of infant interactions (1971). The coding of doll play used by Sears is another example (1951).

Another strategy is to make a running record of the interactions, written in ordinary language. This may be dictated on the spot (see Baldwin and Baldwin, 1970) or reconstructed from memory using notes taken on the spot (Wright, 1967). An ordinary language record

of the interaction is partially precoded because many of the words in ordinary language like *commands, encourages, tries,* or *forbids* are interpretations of actions requiring human judgment. In most cases, this verbal description must be further coded before a completely coded record is obtained. The Baldwins have devised an Interactional Language, a slightly restricted ordinary language, in which the observer describes the interaction. The observer's record can then be coded automatically by a computer program (Ward, 1971). In still other studies, when an electronic recording of the verbal interaction of participants is obtained, this record is then coded by observers of the record.

The choice of what method to employ in producing a coded record depends upon various considerations.

1. What and how many variables are to be assessed. Linguistic variables essentially require an electronic record that can be listened to over and over again (e.g., Brown, 1964). The same is true of most "molecular" variables. If ordinary molar events are being studied, the choice partly depends on how many different variables are needed. If there are only a few easily observed variables, on the spot direct coding is possible and is very efficient. Chapple's (1940) interaction chronograph is a good example and the coding for Interaction Process Analysis can also be done on the spot. Such codings can be fed directly to the computer (either electronically or by human transcriber) for rapid and efficient analysis.

The number of different variables that can be directly coded on the spot is not firmly established and depends on how much interpretation is required. The Baldwins argue that an observer dictating a description in ordinary language can effectively code many more variables than the observer with a check list because he is using a coding system that is very familiar and well-practiced. By computer analysis of such a record, the method approaches the check list in rapidity and efficiency of analysis. For a study requiring assessment of many subtle variables and the making of fine distinctions, the human coding of an electronic record is probably advisable. An additional advantage of coding a video record is that maximum reliability of coding can be maintained. The most serious disadvantage—and it is serious—is that it is very time consuming. Anywhere from 40 to 400 hours of coding may be required for every hour of recorded interaction. Some procedures for adequately sampling the complete interaction is often indicated.

2. The theoretical convictions of the investigator are important in the choice of a method, particularly how much the investigator believes that the variables should be strictly behavioristic with a minimum of interpretation, or that such purely behavioristic descriptions lose all the meaning of the interaction. Generally speaking the less the interpretation, the easier the coding—except that molecular variables like eye movements may be almost impossible to code at all from direct observation. The arguments on each side of this controversy need not be reviewed here. For what it is worth, the authors believe that the observer must interpret what he sees to make it meaningful, but that this interpretation should be at a level of "naive psychology."

3. Finally, practical considerations may dictate the choice of method, for good or for bad. Video recording of wide ranging behavior on the playground takes on the dimension of a Hollywood film production. Where the presence of the observer is a problem, electronic recording may be either less obtrusive or more disturbing, depending on the situation. Generally speaking social psychologists are probably more concerned about the distorting effects of an observer than is realistic.

Thus far, the discussion has centered on the process of recording and coding a segment of social interaction. Another problem is the consideration of the recorded segment of interaction as a sample. One may consider a half-hour play period where the mother is asked to play with her child as naturally as possible in either of two ways. It might be thought of as an actual sample of the totality of the mother-child interactions or it might be thought of as an experimental situation in which interesting mother-child patterns of interaction are revealed. Clearly this particular segment of interaction is best thought of in the latter sense; one uses different mother-child pairs to reveal differences in the playroom; the same mother-child pair behaves differently as the child grows

older (Baldwin and Baldwin, 1970; and disturbed mother-child pairs behave differently from normal mother-child pairs.

But what goes on in the playroom cannot be taken as a representative sample of the total mother-child interaction. There were no other siblings present; the father was not there; there was no possibility for the mother to be washing dishes or doing any of the chores that would occupy her at home. When it is important to obtain a really representative unbiased sample of mother-child interaction in which the distribution of various types of behavior will be the same as they would be if one recorded all mother-child behavior for a year, then something like the full day specimen record (Barker and Wright, 1951) is required and even here the sampling problems were not all solved.

For some purposes the social interactions under consideration may be entirely absent in the detailed observations of parent-child interactions. Bronfenbrenner (1970), for example, describes some major distinctions between parent-child interaction in the Soviet Union and in the United States without ever talking about the variables that would be coded from a sample of playroom interaction. He speaks in the United States of the relative absence of the father, the child's lack of contact with the father's job, the time the mother spends being a chauffeur, and other such descriptive variables. To obtain a picture of what the child's total pattern of interaction is, the environment must first be described in these broad brush strokes and then, when it is important, the interactions within these broad settings can be described in more detail. Barker's work on the description of environmental settings (1968) probably provides the most systematic methods for describing the over all distribution of the child's interactions with other people and the institutions in his total environment.

The investigator thus has many choices in studying social interaction, and for different problems, different aims, strategies, and methods are appropriate. What is most important, of course, is that the investigator be clear about what he is studying and why.

The methodology of social interaction studies should not be left without some discussion of rating scales. Probably more scientific information about the behavior of people in naturalistic situations has come from ratings of that behavior, either by special observers or by other participants in the naturalistic setting than from any other method. The relation between ratings and observational records of social interaction is not always clear. Some ratings may be thought of as summary statements made by the observer. These summary statements could be verified or disconfirmed by actual counts of the frequency of various types of interactions. Thus the cue points for some scales are statements such as "frequently irritated by other people." The analysis of social interaction would lead directly to such summary statements.

Other rating scales like *warmth* or *democracy in the home* cannot be so directly related to the ongoing stream of behavioral interaction. Such judgments can be made reliably under favorable circumstances and must in some way be related to the actual behavior observed. One of the tasks of analysis of behavioral interaction records is to find the cues that in fact lead to such observer's judgments, but the relationship is not obvious. The behavior record is primary data and if it is complete should contain all the evidence for the judgments called for in rating scales. One of the tasks of behavioral analysis is to find the cues on which observers judgments are based. It is important not only for methodology but also for theory. Social learning theory for example is couched in terms of acts. The important research of Sears, Maccoby, and Levin (1957) or Bandura and Walters (1959) finds empirical relations between variables like warmth and personality development but unless warmth is behaviorally defined the empirical relationship cannot be expressed in terms of the theory.

Without in any way deprecating the findings of studies using rating scales, it does seem that their meaning will become clearer through the analysis of the stream of social interaction.

Interaction Patterns in Families of Schizophrenic Patients

There has grown up a respectable body of research using the analysis of interpersonal interactions between the family members of schizophrenic patients. The impetus for this

research came from Gregory Bateson's (1956) description of the "double bind" that he observed in the interactions of parents and schizophrenic children and which led to the term "schizophrenogenic" to describe the interaction patterns in a family that produce schizophrenia in the children. The double bind is a pattern of interaction in which the child receives two incompatible messages from the mother; e.g., to be dependent on her and also to be independent and nondemanding. The major investigators in this area are Goldfarb (1965), Wynne and Singer (1967a, 1967b), Farina (1960), Lidz (1965), Lennard (1965), and Mishler and Waxler (1968). The records of interaction have been obtained from family discussions of topics specified by the investigator, conjoint family therapy sessions or family interviews, or family interactions when the family must produce a joint or consensus response to a projective test like the Rorschach (Loveland, Wynne, and Singer, 1963).

The most careful study in this group is the study by Mishler and Waxler. They recorded the conversation of triads, the mother, father, and child. The child was in some samples a normal child, in others a schizophrenic with a good prognosis as indicated by his premorbid history, in others a schizophrenic with a bad premorbid history, and for every schizophrenic child, there was also a session in which the mother and father talked with a nonschizophrenic sibling of the schizophrenic child.

The conversation was elicited by the "revealed differences" techniques first introduced by Strodtbeck (1958). Each member of the triad responded independently to a number of potentially debatable questions not dealing directly with the family itself.

> An example of such a question is:
> A foreman sees one of his crew taking some company materials home with him. Should he report it or should he just ignore it? Report him ———. Just ignore it ———.

Inevitably the family members did not always answer the questions in the same way. The experimenter would select items on which there was disagreement and present to the family group the individual answers.

Perhaps the mother and father both answered "yes" while the child answered "no." The experimenter then asked the family to discuss the question and try to come to a consensus on it, but a consensus was not required. A session consisted of discussing nine such disagreements, selected so that each member of the triad was originally in the minority on three items.

These discussions were recorded on audio tape, carefully transcribed to retain all the interruptions, and periods of simultaneous speech. The target person for each speech was recorded separately by an observer who noted whom the speaker was looking at, or as in some instances, that he was not looking at anybody. The transcript was divided into unit acts consisting of every clause for some codes and into utterances of a single speaker for other codes. The interactions were then coded in a number of different ways, for responsiveness, effect, focus, interaction process analysis (Bales, 1950), interruptions, and who-to-whom codings.

The result are very complicated and cannot be concisely summarized. In general, however, normal families were more expressive and the affect expressed was more positive but they were more similar to the poor premorbids than the good premorbids. In the normal families the mother and father interacted most with the father having the most power, but in pathological families the patient had a special role; often he and the mother dominated the interactions. Normal families showed more interruptions and simultaneous talking, an unexpected finding in the light of earlier studies. The normal families showed the most responsiveness to each other's remarks.

As the authors are well aware, one cannot be sure whether these patterns of interaction in the schizophrenic families are longstanding patterns of etiological significance, or adaptations to the existence of a schizophrenic child. In order to investigate these questions, it will be necessary to study the interaction of families over a period of time before the child develops schizophrenia and determine whether the patterns of interaction discriminates between the families where the child does become schizophrenic and those where he does not. Since only some 2 percent of a random sample will develop schizophrenia it will be necessary to choose a vulnerable sample where schizophrenia is more likely. One kind of vulner-

ability is genetic, where one or both parents have had a schizophrenic episode. There are more than two possible outcomes for children genetically vulnerable to schizophrenia. A sizable percentage show more or less serious disturbances short of diagnosed schizophrenia (Heston, 1968; Kety, S.S., Rosenthal, Wender, and Schulzinger, 1968), but also there are completely normal outcomes.

In some studies the investigators have found discriminable differences among familes with a schizophrenic young child, those in which the disease appears in adolescence, and families with a child with other kinds of disturbances (Singer and Wynne, 1963). These studies, however, have not actually studied family interaction, but only the responses of the parents on various psychological tests.

It would be valuable to study the interaction process within families of children with various types of emotional disturbance and other types of handicaps. The revealed difference technique has proved valuable for eliciting conversation in many studies, but whether it is the best technique for families with disturbed children is not determined. For families with very young children, it would probably be unsatisfactory because of its verbal demands, but Loveland, and Wynne, and Singer (1963) have used the family Rorschach with young children. Other settings creating family interaction need to be developed. The interactions in families with older children can be captured reasonably well through the verbal exchanges, but for preschool children the nonverbal interactions in play would also need to be analyzed.

The study of family interactions in families with a schizophrenic child undoubtedly became popular because of their potential contribution to determining the etiology of schizophrenia, but we now know that a handicapped child, from whatever cause, creates a situation to which the family must adapt. Therefore such studies as these will be valuable in the study of families of all handicapped children. Barker for example, has contrasted the record of a full day's activity of a child with a serious heart defect with a normal child of the same age (Barker and Wright, 1955). Farber (1959, 1960, 1968) has extensively studied the effects of a mentally retarded child in the family but many more studies are needed to understand the coping mechanisms of children and families and how they fit together.

Naive Psychology

A representative research program utilizing this psychological approach is that of the Baldwins (1970). They take as a premise that one person's interpretation of another person's behavior involves some tacit beliefs about human behavior, really an implicit theory of behavior. For example, a mother praised her child for completing a puzzle by commenting that he had done it all by himself. The belief that he would be pleased by such a comment depends upon an assumption that more ability is required to succeed without help than with help. Thus what she communicated was praise for his ability. And he, by age 5, obviously understood what she meant.

This implicit common sense psychology has been described by Heider (1958) under the label of "naive psychology," utilized by the Baldwins as the theoretical basis of their description of mother-child interaction. Its basic assumption is that behavior is intentional, that this intention is lawfully related to the motivation of the actor, and that the success with which the intention is carried out is a function of the individual's ability and his effort.

Assuming that ordinary people believe that such factors as these influence behavior, one can understand some of the techniques they use to influence each other. For example one person may try to persuade the other that some action is in the other person's best interest, or he may try to convince the other person that he ought to do it, or he may ask it as a favor.

People do not expect that everybody will behave the same way. There is plenty of room for individual differences within naive psychology. For example one person is bossy and tries to command people to do what he wants; another is tactful and tries to persuade them. Both are understandable in terms of naive psychology. But people do expect that a person's behavior will be consistent with naive psychology and some kinds of behavior are not easily accounted for. Thus if A dislikes B and A benefits B, the behavior is a puzzle. The observer, trying to make sense of it in terms of naive psychology, may search for

some disguised self-interest behind the action, or possibly some moral obligation. When a person's behavior becomes completely inexplicable within naive psychology, he is judged to be eccentric, peculiar, unpredictable, even frightening because he cannot be counted on not suddenly to turn hostile and destructive.

Emotionally disturbed people are not the only ones who do not behave in accordance with naive psychology; others are infants and very young children. There is, in fact, a sort of naive psychology of infancy, which assumes that some of the usual factors are operative in their behavior, but others are not. For example, we attribute pleasure and pain to infants, but do not expect them to understand a threat of punishment and refrain from some behavior on that account.

As an infant grows he gradually acquires the ability to understand the naive psychological meaning of other peoples' actions just as he acquires the ability to construct and comprehend meaningful sentences. This socialization process is not well understood, even less than the acquisition of language, to which it seems closely related. One part of the Baldwin's research program is directed toward the study of mother-infant interaction.

At any rate most children do acquire naive psychology in the first few years of life. But some children, for various reasons, do not develop normally and fail to respond as expected.

What may happen when parents have coped unsuccessfully with a child, and have not found him learning to respond to the ordinary social influences, is that they may give up and shift their whole conception of the child from that of a normal person into something infantile or even something not quite human. One mother for example treated her seriously disturbed 4-year-old almost like an animal pet, physically petting him, even whistling to him.

Such a disturbed child is, of course, not like a normal child of his age and his behavior is not easy to understand. Skillful teachers, expert therapists, and wise mothers may gradually acquire an understanding of how such a child is different, and treat him in a way that capitalizes on what is normal about him and thus help him become more normal. What is difficult for mothers in such circumstances is that their (and our) naive psychology does not encompass the child's particular deviance from normality as it does the fidgety restless child, the day dreamer and run-of-the-mill problem child. Once outside the range of naive psychology, we are at a loss unless we have acquired some special understanding of particular kinds of difficult children.

Utilizing concepts derived from naive psychology, the description of mother-child interaction that emerges from the Baldwins' study includes such variables as the following for the mother and the child separately.

Number of nonsocial acts—
Number of social acts—

a. Behavior requests
   1. Type of act requested
      a. physical b. mental
   2. Type of influence technique
      a. requesting b. commanding
      c. coaxing d. persuading
      e. begging, etc.
   3. Frequency of compliance
b. Information requests
   1. What kind of information
      a. what b. where c. when
      d. why, etc.
   2. How frequently answered and how completely
c. Information-giving acts
   1. Types of information (see above)
d. Attempts to cause other person to feel
   1. Types of feeling
e. Expressions of feelings
f. Requests for permission

It can be seen that these overlap with those from Mishler and Waxler (1970) but include some they do not try to measure and do not include some that they find important.

Preliminary analyses have indicated that on such variables as those listed above, there are striking differences in the moment-by-moment interactions between a disturbed mother-child relationship and one where it is relatively normal.

The Baldwins' project is merely an example of various studies of social interaction using a generally similar approach. Whiting's (1970) and Caldwell (1967) are two others. Still others are more concerned with the formal interaction of the teacher with a whole class than

the person-to-person interaction focusing on teaching methods (e.g., Flanders, 1960).

Another strategy for studying social interaction was developed by Barker and Wright (1955), adapted more to the analysis of interactions of the child with all the people in his environment. One of their central concepts is the "episode," usually much longer than a single act. Episodes are units of activity like "going to school," "playing baseball," or the like. These episodes break the child's day into reasonable size units, and then each episode can be coded to describe the type of activity, who were the child's associates, was the episode gratifying or frustrating, and so forth.

The investigator who wishes to study the interpersonal interactions of disturbed or handicapped children with the significant people in their environment thus has a number of techniques from which to choose the one best suited for his purpose. The indications of available research are that such studies will be profitable; i.e., differences attributable to the handicap or disturbance will be found. Such studies can also be utilized to explore more thoroughly some of the findings that already have established the relationships between such distance variables as social class, parental attitudes, and the child's attitude toward himself on the one side and mental health and personality adjustment on the other.

Social Reactions to Handicapped Children

An earlier discussion suggested that some of the patterns of interaction between the child and the people in his environment may be due to the kind of expectations that disturbance or handicaps arouse in other people. While there have not been many careful studies of such attitudes toward the handicapped child, the study of person perception has been investigated in social psychological research. Many of these same studies would be very useful in analyzing more carefully how people perceive and conceive of the disturbed or handicapped child.

Let us begin with one important investigation of opinions of handicapped children carried out by Richardson and his colleagues (1964). Many studies of social opinions collect data from the respondents' answers to a predetermined set of questions, but such a procedure presupposes considerable background knowledge about what questions to ask and how to ask them. Richardson began with a much more open ended approach in a camp organized primarily for handicapped children but with about half of the campers not handicapped physically in any way. The campers were from the lower socioeconomic levels. Richardson began by asking handicapped children and their nonhandicapped camp mates a very open-ended question, "Tell me about yourself" or "tell me about Jimmy or Sally," naming some person the child knew in camp. The responses to this type of question were categorized into various expressions of attitude.

The clearest finding is that handicapped children themselves refer less often to such matters as locomotion, physical ability, and occupational activities. They also refer less often to interpersonal relations with people outside the family, or even to other members of the family except the mother, to whom they refer more often than nonhandicapped children. They refer more often to the handicap itself, and are more prone to general negative comments and to concerns with the past.

Preceding this study, Richardson and his colleagues (1961) had investigated much more specifically the attitudes of people to different kinds of handicap. They presented line drawings of six different children to a large sample of subjects. The pictures included a nonhandicapped child, one in a wheelchair, one on crutches, one with an arm amputated at the elbow, one with a facial disfigurement, and one obese. The subjects were merely asked to rank order the pictures in terms of how well they liked the people.

It turned out that there was considerable consensus in the rankings. The normal child was ranked highest, then followed the wheelchair child, the child on crutches, the amputee, with the facial disfigurement next to lowest and the obese child as least liked. The stereotyping of the differently handicapped children is rather shocking, particularly since the pictures were not extreme. The facial disfigurement was not very noticeable, just a one-sided smile that carried little of the emotional impact of a live person with a serious facial disfigurement. Similarly the picture of the obese child was not nearly as extreme as it might

have been. The fact that there was so much agreement in the rankings suggests that the pictures were really just symbols of a type of handicap and that there are clearly stereotyped attitudes toward different types of handicapped people. It is hard to believe that the ranking is specific to these pictures; in fact the same results were obtained with a set of pictures of girls as well as boys. These questions need to be resolved with further research. Would a mere verbal label elicit the same results?

Data already show that not all groups agree on this ranking. Richardson and his colleagues (1963) predict that children from lower economic level Jewish and Italian families would not rank obesity and facial disfigurement as low because of the high value put upon food in those cultures and, particularly for the Jews, because facial characteristics are such a salient hallmark of Jewishness. These predictions were confirmed, although the Italian sample still rated obesity at the bottom of the rank order. Furthermore, an institutionalized psychiatric group and an institutionalized mentally retarded group ranked the pictures in atypical orders, but there was no obvious reason for the rankings. A noninstitutionalized mentally retarded group did not achieve a consensus among themselves in the ranking.

These differential preference are persumably reflected in the actual treatment of handicapped children in naturalistic situations. From social psychological research indicating the negative effects of physical weakness and lowered self-esteem on peer popularity, one might easily predict that handicapped people would be rejected. There is much scattered, largely anecdotal evidence that a handicap does indeed influence social reactions, but it does not indicate that this reaction can be described simply as rejection. That element enters into it, but sympathy is aroused; guilt and embarrassment are also commonly present. Ambivalence is probably the best single term to describe people's reaction to handicaps. Unfortunately there are all too few careful systematic studies of the actual interpersonal behavior of handicapped people.

These studies represent the application of well established methods of social science to the study of handicaps. One of the clear principles of social judgment is the "halo effect" first labeled by Thorndike (1920). A person who is judged as able and competent in one area of activity is generally overrated in the desirable direction on many traits that are not realistically related to the first. Thus, for example, people who have high status sociometrically are characterized as generous, enthusiastic, and affectionate (Lemann and Solomon, 1952). Also some personality traits seem to be more central than others in terms of influencing social judgments. Asch, for example, found that if a list of personality traits was given to a judge, the adjective "warm" or "cold" seemed to be central. If two lists of traits was identical except for a change from warm to cold, the whole picture created by the list was markedly changed whereas a change in other traits was less influential (Asch, 1946). Also the trait listed first in the list tended to be more influential than traits further down in the list (Shapiro and Tagiuri, 1958).

This tendency for some aspects of the person, or for those aspects that are most salient, to influence the total picture of the personality seems certainly to affect the social judgments made of handicapped people. In fact there is considerable basis for believing that psychologists and educators have fallen into this same type of error in treating the IQ as if it were a general index of effective adaptability. If one takes a large battery of intelligence test items, it is generally established that there is a positive correlation among those items, and that this "g" factor can be measured by various intelligence tests. What seems to be the erroneous assumption is that effective social functioning is highly correlated with intelligence, and this assumption has many consequences for the treatment of such people. Let us examine some of the data about mentally retarded people to illustrate this general point.

As Zigler (1967) has argued cogently, there is good reason to think IQ is distributed rather peculiarly over the general population. There is a hump in what looks otherwise like a normal distribution, and this hump is at the lower end of the distribution. This shape of the distribution is an established fact and has been interpreted various ways (Jensen, 1969; Zigler, 1967). Zigler's interpretation is that there is a group of mentally retarded people, with a mean

IQ below 50, probably about 35, which represent those cases where there is a clear physiological defect. Cretinism, phenylketonuria, and mongolism are all examples of such a clear defect. Usually the consequences are quite severe, and there is little question but that such a severe defect often prevents the person from adapting effectively to the complexities of everyday life. The case for mongolism being so serious a handicap is not so clear and will be discussed more fully later.

If one removes these cases from the distribution, Zigler argues that the remainder would show a good normal distribution and that the mentally retarded people at the bottom end of this normal distribution represent those unfortunate people in whom so many of the factors influencing intelligence (genetic, prenatal, perinatal, and postnatal environment), have happened to be negative that they represent the case of the unfortunate gambler who was betting on red when 12 blacks came up in a row. He argues that they are just as much a part of the normal distribution as those people with IQ's above 130 or those with IQ's near 100—which does not mean that their IQ scores are in error or that the individual's score will be readily changed. Changeability of IQ is a separate problem, not inherently part of the present argument.

There is no question but that the IQ has historically been geared to the selection of children who will do well or poorly in school. Binet and Simon's original test was an attempt to select children who would do poorly in school (Binet and Simon, 1905). While some attempts have been made to broaden the base of intelligence tests beyond academic aptitude, they have not been very successful. As a consequence the children testing below 60 or 70 in IQ find school a great crisis period. They are vulnerable to the demands of school. During the preschool period they do not fail spectacularly to adapt to the social demands of their environment, and after they have left school they may function quite effectively.

"Graduates" of institutions for mentally retarded children may show a surprisingly normal distribution of outcomes. Many of them marry and hold down respectable jobs; they show a fair percentage of people owning their own homes and not being on welfare. Their average socioeconomic level is lower than the general average and they are vulnerable to unemployment, but the important point is that many of them function passably outside an institution whereas earlier they were not able to function effectively in school—or at least in school-related tests (Kennedy, 1948; Bijou, Ainsworth, and Stockey, 1943).

The American Association for Mental Deficiency recognizes this discrepancy between test functioning and social effectiveness in their criteria for mental retardation, which includes retardation of more than one standard deviation on IQ and also retardation of more than one standard deviation on social adaptability (Heber, 1959). Obviously both criteria should be employed in deciding on such a drastic action as institutionalization.

The trouble is, of course, that measures of social effectiveness are very poorly developed by comparison with tests of IQ. The Vineland Social Maturity Scales was an early attempt to assess this type of functioning, but it leaves much to be desired. Other measures are usually some form of rating an occuptational skill or social adequacy.

One problem in developing an effective test of social adaptability is the lack of a clear criterion measure which samples a wide range of social situations. One direction for research it to attempt to assess the child's adaptation to his natural environment. How effectively and by what means does he attain his goals in his environment? Since goal achievement in the natural environment may be a function of adaptability, it also seems desirable to develop social functioning tests, perhaps along the lines used in the OSS assessment program (Murray, 1948). The problems to be solved in such a research program are serious ones, but the fundamental problem of measuring effective functioning in naturalistic situations needs very much to be attacked.

Self-Esteem of Handicapped Children

This discussion of the social evaluations of the handicapped child of course raises the question of the child's self-esteem. The belief that handicapped children tend to have low self-esteem is widely held though not clearly established, and in any case the characteristics

that ordinarily go along with low self-esteem may or may not hold for handicapped children.

We might begin with a sort of naive psychological view. In the naive psychological belief system, when a person thinks he cannot do something, he will not try to do it. The handicapped child, by definition, cannot do some sorts of things and an essential part of his adaptation is to recognize this fact realistically. The danger is that the child will generalize his limitations and believe that he cannot achieve any of the goals he wants. Such a general lack of self-regard then prevents him from striving to use a prosthesis, perhaps, or searching for a job that is both rewarding and within his capabilities.

It is clear from Richardson's findings that handicapped children, when telling about themselves, say things that reflect their limitations, but it is not easy to find out which limitations are realistic and which are unnecessarily self-imposed, or unnecessarily imposed by his parents. Once again the actual observation of the activities of handicapped children would provide very useful information on this question.

There is a wealth of scattered unintegrated research on the psychological correlates of self-esteem. Usually self-esteem is measured by a direct questionnaire, sometimes by asking the child to report on his ability in a number of specific areas (Sears and Sherman, 1964), or sometimes by a Q-sort in which the subject judges his own traits and also his ideal. The discrepancy between the two is a measure of lack of self-esteem. In general the findings indicate that people with low self-esteem are high in the need for social approval (Janis and Field, 1959) and thus vulnerable to social influence. There is a general tendency to find that low self-esteem is correlated with various measures of maladjustment and neuroticism (e.g., Leary, 1957), but in many studies the relationship is curvilinear, with both excessively high and low esteem being related to lack of social adaptability. In the case of handicapped children, the relationship may include the opposing tendencies to deny the handicap and/or to be devastated by it. Cohen (1959) has suggested that level of self-esteem is related to the choice of defense mechanisms.

In view of the many methodological and theoretical problems in the study of self-esteem, careful work on handicapped children would be theoretically valuable to social psychology as well as useful for educating and counseling such children.

If it is true that the major adjustment problem facing the handicapped child is the combination of other people's reaction to his handicap, and his own self-esteem in the face of it, the question arises whether handicapped children should be segregated into special homogenous groups or should be kept in normal social institutions and integrated as much as possible with nonhandicapped children.

Some people point to the many examples where children are teased by their classmates, where they must compare themselves to nonhandicapped people all of the time; such people argue that this is both unkind and psychologically damaging to the individual.

The arguments on the other side are for integration. The segregation of children into special groups, specifically labeled, may create exactly the kind of damaged self-esteem that we have been discussing. The argument is that freely mixing children of all sorts presents a realistic environment in which the handicapped child can best learn what he can and cannot do and how to cope with his problem. While the incidents of teasing or worse will certainly occur, they are less damaging than segregation. Adults need to be alerted to the possibilities of teaching both the injured child and the one performing the injurious act more desirable ways of dealing with the handicap. Also, the presence of handicapped children will be helpful to the nonhandicapped children; they too need to know about the existence of handicaps and learn how to deal with handicapped people without becoming contemptuous or oversolicitous. The people who support this view are not just sentimentalists; experienced teachers who have seen such integrated groups are among those who favor it, although equally experienced teachers may also disagree.

It is probably clear that the authors are inclined toward the integrated viewpoint. The effects of institutionalization are well documented although not for all types of handicapping conditions. There is some evidence that institutionalized mentally retarded children progress less well than those kept in the home community (Sievers and Essa 1962). Further-

more, there is a great deal of evidence that institutionalized children show a number of effects of social deprivation, particularly their dependency upon a warm adult when one is available.

But institutionalization is an extreme form of segregation and is not the same as segregation into special classes in school. This question cannot be resolved at present because there is so little evidence on which to base a sound judgment. The need for further research is obvious.

Summary

In summary this chapter has been devoted primarily to the belief that the most neglected field of study and one of the most promising ones is the actual observation of handicapped children of all kinds in their families, in school and in other naturalistic situations. While the problems of doing such research are formidable, they are not insurmountable and the potential yield more than makes up for the difficulties.

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